# Maritime science and technology:

## Changing our world

Nigel Watson

Managing Editor: Barbara Jones

Lloyd's Register

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Lloyd's Register Foundation

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# Contents

# Foreword

**With the opening of our Global Technology Centre on the campus of the University of Southampton, five years after our 250th anniversary, I decided to mark the occasion with a technology book to sit alongside our corporate history book.**

I have long championed the role of naval architects and the contribution that they, together with marine engineers, have made to the changing world of global economics. Without the advanced drill ships and VLCCs developed by these highly skilled professionals, how could we distribute oil – the substance that currently powers the planet – from source to refinery to user? Without 18,000 teu container ships, how could China have become the world's factory? Without Capesize bulk carriers, how could the huge quantities of iron ore be taken to the ever-hungry blast furnaces that turn it into the steel so vital to our western society?

Did the marine sector drive the developing technologies? Or did it just adopt them? It would appear that the former is the case - as the industry has moved from sail to steam, from steam to internal combustion engines, from wood to steel and to increasing sizes and types of specialist vessels - the pioneers of naval architects and marine engineers have applied the latest technologies, and our global society has benefited.

Looking into the future, the technologies are becoming ever more diverse and more complex at an increasingly rapid rate, including nanotechnologies, big data analytics, LNG fuels, hydrogen cells, autonomous operations, advanced materials and human factor interfaces. It has become abundantly clear that Lloyd's Register (LR) by itself cannot possibly stay at the leading edge of all these sciences and technologies.

But nevertheless, with LR's mission to enhance the safety of life, property and the environment, we have to approve their application; that is the reason for our very existence. So now that the University of Southampton, through investment in our Global Technology Centre, has become our partner in that goal, we are confident that we can continue to fulfil our mission reliably and responsibly.

This book attempts to document those developing technologies and the ways global economics have changed as a result. I hope you enjoy the read!

Richard Sadler, Chief Executive Officer,
Lloyd's Register Group Limited

**The University of Southampton gained its Royal Charter in 1952; it was the first university to be created by Her Royal Highness Queen Elizabeth.**

For more than half our history as an independent university, we have been collaborating with Lloyd's Register, bringing our strengths in engineering, science and technology to bear on real industrial challenges. We are incredibly proud of the joint engineering campus which has been created here in Southampton, with the promise this holds for developing the technologies of the future. In 2014, the university was rated number one in the UK for its research quality and volume in engineering, a great testament to the strength, and the depth of knowledge, of our academic staff. Working together with Lloyd's Register, we believe we can keep the UK at the forefront of engineering technology for the next generation.

Professor Don Nutbeam, PhD, FFPH,
Vice-Chancellor, University of Southampton

# 1 Towards a revolution

The ship has been fundamental to the process of globalisation. Integral to this transformation has been the significant contribution of countless naval architects and marine engineers. They were able to take advantage of the many new technologies that accompanied industrialisation, enabling the ship as the world's principal cargo carrier to set the pace for the expansion of international trade. In this evolution the classification societies too would play an important part as they developed their own research capabilities and analysed their survey records in order to assess the way in which ships were changing.

At the time of the foundation of Lloyd's Register as the world's first classification society in 1760, there was a boom in world trade, but there had been little innovation in ship technology; the average sailing ship was still small and the science of naval architecture was still elementary, even though innovative shipwrights built many different types of sailing vessel. Very soon, however, with the application of steam power to shipping, all this would begin to change and the pace of development would increase.

Lloyd's Register (LR) became the world's first classification society in 1760. In the intervening 250 years LR's story has been intertwined with almost every important advance in ship technology, from sail to steam or wood to iron and steel, from riveting to welding, from the general cargo ship to the containership, as shipping has shaped the world.

The changes wrought by globalisation would have been unachievable without the ship. Advances in technology, derived from flashes of genius, mainly driven by commerce, and developed by talented scientists and entrepreneurial engineers, transformed the wooden sailing ship. The metal steam ship was one of the technological marvels of its age, capturing the public imagination. Bigger, faster, safer and more efficient, it proved supremely flexible, evolving into a variety of specialised vessels in response to the growing volume and more complex nature of world trade. The pace of this cumulative technological change may have been evolutionary but its impact was revolutionary.

In 1788, when the first steam-powered passenger voyage took place, the largest ships in the world were the stately British East Indiamen. The *Lascelles*, for example, built in 1795, was 1,426 tons (bm), 175 feet long, 43 feet across the beam, with a draft of 17 feet, carrying a crew of around 150 men, but with a speed of just a few knots. Less than 30 years later, in 1821, the first sea-going iron steamship, the *Aaron Manby*, was launched. By 1858 the world's largest ship was Brunel's iron-built and steam-powered *Great Eastern*. Launched in that year, she was 18,915 gross registered tons (grt) and 692 feet long, capable of 14 knots, carrying up to 4,000 passengers, with a crew of more than 400. Yet in the same year the first steel-built vessel, the *Ma Roberts*, was also built, and within a generation steel steamships, lighter, faster, stronger, had become the elite of world shipping.

LR, and the other classification societies that followed in its wake, played an important part in this process of technological change. They originated because of the pressing need for a reliable system of assuring merchants and insurers about the condition and safety of ships as the value and volume of seaborne trade increased. With the gradual adoption of new forms of propulsion and new materials as well as the carriage of new types of cargo, the societies found it necessary to validate the new technologies on behalf of their clients.

They began to gather data and develop technical expertise, which proved immensely valuable in helping to overcome the challenges facing those who were adopting the new technologies, while the best of the surveyors and engineers they employed were of the highest intellectual calibre. Through practical research and learned papers they contributed towards the growing reputation of naval architecture and marine engineering as these disciplines moved from empiricism towards applied science. Without the classification societies, the transformation of the ship and shipping would have been much more problematic.

The ship has made a fundamental contribution to the way in which the world has changed so dramatically over the last 250 years, a process underpinned by the invaluable role played by the classification societies. The story that follows is based on the contributions made to maritime history by many authors over the years, and draws on the expertise of LR staff and others in looking to the future.

Technology, science and engineering are the key themes. Technology has been defined as the creation of tools or artefacts to achieve a specific purpose; science as the theoretical explanation of physical phenomena based on empirical data or fundamental mathematics; and engineering as the application of scientific theory to the process of creating technology based on an understanding in advance of its creation of the characteristics and purpose of that technology.

These form part of the process of technological change, defined as invention, where the application of scientific knowledge or principles leads to a new product or process; innovation, with the commercial application and further development of an invention; and diffusion, that is, the widespread adoption of an innovation.[1] The question was whether innovation in shipping was the result of commercial demand or the availability of new technologies and improvements in science.Globalisation is a concept that seems to defy consensus in definition. The word was coined relatively recently to cover the process of global economic and social convergence and integration. Many insist it can only be applied to the world after 1945 or even later; but equally there are many who see globalisation as describing a process as old as time itself; one that began in limited geographical areas, steadily working outwards as technology advanced and economies developed, moving beyond national boundaries and across the oceans, before stretching across most of the world. Christopher A Bayly, for instance, in his work on the birth of the modern world between 1780 and 1914, noted how 'Empires and commercial expansion had created multilateral links between different world societies which tended towards greater uniformity'.[2]

Developments in the west are a central feature of this story of globalisation, especially since the UK was the world's leading maritime nation throughout the nineteenth century and much of the twentieth. This dominance is reflected in much of the literature on maritime history, although the global spread of the British merchant marine does extend the story beyond UK shores. In more recent times, the accelerating process of globalisation has diminished this Anglo-centricity as we look to the influence of innovation in places as far afield as South Korea, China and Japan. Although the growing dominance of countries in Asia is truly remarkable, any author limited to a single language, English, is still faced with a relative paucity of material on the shipping history of other nations.

By the time LR was founded, shipping had long been opening up the world. Some historians suggest that the first steps towards globalisation came in the fifteenth century with the development of the revolutionary Portuguese caravel. This small but fast and highly manoeuvrable round-hulled vessel, exceptionally well-suited to sailing into the wind, took European sailors beyond the limits of the known world, linking Europe by sea for the first time with Asia and America. Pioneering voyages paved the way for the intense rivalry between the Portuguese, Spanish and Dutch, as the masters and men of their merchant marines learned how to use the winds of the oceans to their own advantage and fought to exploit the new riches of the distant world. The rapid exchange between the continents of crop species, such as corn, wheat, coffee, tea and sugar, transformed agricultural and labour markets. By the mid-seventeenth century 'goods of all kind and people of all nations ranged over most of the globe'.[3] Silver mined in Mexico and Peru created a new global monetary system in the Spanish *real* while the precursor of today's global commercial enterprises, the joint stock corporation, emerged. By the mid-eighteenth century, supremacy at sea belonged to the British, thanks to naval successes, the riches of the American colonies and legislation (the Navigation Act) giving their ships a monopoly in home ports. The activities of international corporations like the Honourable East India Company (HEIC), whose stately vessels were the largest cargo carriers on the oceans, created global markets for exploitation by the new industrialists beginning to emerge.

Henry Martyn was among the earliest to give voice to this credo in 1701, emphasising at the same time the inextricable link between shipping and trade, as he wrote how 'we only plough the Deep and reap the Harvest of every Country in the World'.[4] The HEIC rose to account for half of the world's trade; it ran the cotton trade, creating a European mass market that displaced silks and woollens. This could be said to have fostered the modern fashion industry and consumer society, as for the first time, in certain circles clothes were discarded not because they were worn out but simply because they were unfashionable. Shipping therefore was capable not only of expanding trade worldwide but of facilitating the development of entirely new industries.

As a result of these opportunities, British trade doubled in volume and value between 1700 and 1750. It continued to accelerate, rising faster than the growth in population or total output, while exports as a share of industrial production rose from a fifth to a third. As for imports, improving wealth made previous luxuries increasingly affordable for some sectors of society. As historian David Richardson observed, slave-grown sugar accompanied imported tea drunk from imported porcelain. Slavery was a significant part of British trade, with British traders estimated to have carried around three million slaves from Africa during the eighteenth century, a trade that peaked in 1783. During the eighteenth century, tobacco and sugar were the two most valuable staple imports into Bristol, while the export of manufactured goods from this and other British ports also grew in importance. Hull exported lead, cloth and corn and developed Northern European trade links with Scandinavia and the Baltic, importing timber, iron, flax, yarn, hemp and naval stores. Hull also developed a central role in the coasting trade providing a link with London and central England.

The accumulation of capital generated by this commercial revolution, as well as the need to further expand trade to furnish the demands, nutritionally and otherwise, of a nation expanding in numbers and wealth helped to facilitate the onset of economic change. 'Rising demand, high wages, the shortage and inflexibility of skilled labour then created a great stimulus in the mid-decades of the century to innovation, mechanical advance and an eventual break-through to new forms of power, materials, machines and factory production'.[5] Change would come through a combination of inventive genius, empiricism rather than applied science, and commercial imperative. As each new technology stimulated increased productivity and increased fixed costs, so too it would stimulate the further search for more innovations to boost profits and cut costs.

By 1750 almost half of all British ships were involved in transatlantic trade. The expanding British merchant marine was carrying most of the world's trafficable goods and in the long-distance overseas trades there was already growing specialisation, with many ships making the same voyage year after year unless disrupted by war. But while more ships set to sea, their dimensions remained largely unchanged. The largest British sailing ships, the British East Indiamen, were no larger than the largest Spanish galleons of the sixteenth century, while the average British merchant ship of the late eighteenth century was still small, just 100 tons. Moreover, on transatlantic routes the cost of transport, hindered by war and trade monopolies, remained high, with most imports into Europe confined to high value, low volume goods. At the same time these valuable cargoes were carried in unsophisticated conditions, their neglect resulting in frequent claims against masters and ships. Today the reverse is the case, with an enormous volume of differing goods carried safely across the oceans in modern ships.

Commercial interests would drive the adoption of many of the as yet unknown new technologies, and it was the value of trade and concern for safety that lay behind the formation of the Society for the Registry of Shipping, as LR was originally known. Merchants increasingly wanted assurance that the ships carrying their precious cargoes across the oceans were structurally sound and in the hands of experienced masters, as did the underwriters who insured them. The *Register Book* published by the Society in 1764 classed ships according to the condition of their hulls and equipment. Moreover, the *Register Book* also named the master of each vessel, allowing charterers and insurers to check their reputation. Within years the *Register Book* had become an indispensable aid for merchants, underwriters and passengers and the term 'A1', the highest grade of classification, became a byword for the very best. Here was an early indication of the value of knowledge as recorded data.

In 1707 a man-powered paddle-boat built by Denis Papin, a French-born mathematics professor, was demonstrated on the River Fulda in Germany but quickly destroyed by outraged local river-men. By 1760 there had already been several attempts to apply steam power to marine propulsion. Subsequent attempts by others met with no more success. Despite the improvements made to the steam engine by Newcomen and Watt, there was little further progress in applying steam to ships before the end of the eighteenth century.

By then there had been a concerted effort to develop a more scientific approach to ship design. Naval architecture, denoting in particular the application of geometry to ship design, had been defined in the early seventeenth century and the term was widely used throughout Europe by the 1700s. At the same time, evolving theories of mechanics, such as hydrostatics and fluid dynamics, were being applied to ships. By the late seventeenth century, towed models were already being used in their experiments by Christiaan Huygens and Samuel Fortrey, while the initial measure for calculating the stability of a ship, the metacentre (which can be considered as an imaginary point of suspension), was developed by the Frenchman Pierre Bouguer in the 1740s.

Treatises began to appear on the subject. One of the earliest was the *Doctrine on Naval Architecture* by Anthony Deane, the Master Shipwright at Harwich, in 1670. Westcott Abell, the eminent naval architect and onetime Chief Ship Surveyor for LR, considered that Deane's work 'may be taken as the first step to apply a knowledge of science to the shipwright's craft'.[6]

But Deane's work was largely ignored in England and it was the French who led the way in naval architecture during the eighteenth century. The Inspector-General of the French Navy, Duhamel du Monceau, founded the École de la Marine, the first School of Naval Architecture, in Paris in 1741, which had an intermittent existence until it was forced to close during the Revolution. The Académie Royale de Marine, founded in Brest in 1752, met a similar fate. Nevertheless, William F Stoot, reviewing the contribution of long-forgotten pioneers such as Hoste, Bourde de Villehuet, de Missiessy Quies and the Comte de Buffon, concluded that 'the amount and scope of experimental work on ship resistance carried out in the seventeenth and eighteenth centuries is truly staggering'.[7] The role of the French state in this process stemmed partly from the desire of naval authorities to achieve greater control over shipbuilding and greater standardisation of ship design.

All this theorising resulted in little practical benefit. First, many scientists were concerned more with the outward form of the ship rather than the application of science. Second, much research was either inadequate or incomplete; in France, for instance, the continuity needed for further progress was disrupted by the Revolution. Third, published works were often difficult to understand, or were published in other languages such as Latin, and in any case many practising shipwrights were unable either to read or write well, if at all, these skills seen as unnecessary for their trade. As one writer observed in 1697, shipbuilding was a very imperfect art, even the best shipbuilders relying largely on their eye, with similar ships displaying great variations in their characteristics. Master shipwrights were not unskilled, having spent years learning their craft, and capable of applying arithmetic and geometry, but their expertise came almost entirely from accumulated experience. While academic treatises may have been inaccessible to them, shipwrights instead learned from each other. Danish apprentices, for instance, were sent to train in English and French naval yards, while the Spanish drew on the talent of English and French shipwrights.

Pierre Bouguer appreciated the importance of disseminating knowledge as widely as possible and deliberately wrote his *Traité du Navire*, published in 1746, in more accessible language in an attempt to reach a wider if still limited audience. He understood the empirical nature of shipbuilding but he also recognised its limitations, writing that experience 'would be the best means of perfecting naval architecture, if it were possible; but it is plain enough that practice is insufficient in many cases'.[8] In Britain the repetitive design of naval vessels continued to perpetuate common faults, notably too little freeboard and inadequate stability, entrenching a conservative approach to change.

The difficulty was bridging the divide between theorist and practitioner, a problem that has not been entirely eradicated today. The theorist often had little experience of practical shipbuilding while the practitioner derided the failure of attempts to apply imperfect scientific analysis to their trade. An attempt to cross this chasm was made by Fredrik af Chapman, a Swede of British descent. Chapman, the Chief Naval Architect of the Swedish Navy, was an innovative designer and capable manager who reorganised the Swedish naval yards. He combined his practical experience and theoretical knowledge in extensive writings on shipbuilding.

## Anthony Deane (1638–1721)

Sir Anthony Deane was a Naval Architect and Master Shipwright during the seventeenth and eighteenth centuries. He was also Mayor of Harwich and Member of Parliament (MP).

In the late 1650s, Deane worked as an apprentice under Christopher Pett, the Master Shipwright at the Woolwich Dockyard. After finishing his apprenticeship, Deane was made the Assistant Master Shipwright.

At just 26 years old, he was appointed the Master Shipwright of the Harwich Dockyard, a prominent naval base. Deane was believed to have been given the job due to his friendship with Samuel Pepys – a member of the British Navy Board. Pepys himself allegedly recommended Deane for the job stating he was *'a conceited fellow, and one that means the King* a *great deal of service'*. Deane's engineering and scientific abilities shone through during the mid-1660s, when he built a number of ground-breaking vessels for the Royal Navy such as the *Harwich* and *Resolution*.

At the end of the Second Anglo-Dutch War in 1668, the Harwich Dockyard was closed as the demand for warships had drastically dwindled, and so Deane was transferred to Portsmouth, where he again held the job of Master Shipwright. Four years later, he was promoted to Commissioner, a job which entailed his becoming an active member of the British Navy Board – and also relinquishing his role as the Master Shipwright of the Portsmouth Dockyard. Subsequently, Deane was able to pursue shipbuilding once more, a passion he had held for a numbers of years.

In 1673, Deane, now 35, was knighted and appointed the Controller of the Navy's Victualling Accounts, a job which required him to ensure that sufficient food and medical supplies were provided to sailors. A few months later, Deane, having become an alderman, funded the construction of a new guildhall and jail within Harwich. His efforts for the Harwich community unsurprisingly led to his election as Mayor of Harwich. Within the political realm, Deane was also made the MP for Harwich along with his close friend, Pepys.

Controversy soon followed, when in 1679 Pepys and Deane were accused of leaking naval intelligence to the French put on trial for treason and briefly imprisoned in the Tower of London, but after a brief spell in jail, the pair were released without charge. He had links with Peter the Great and is thought to be among the best of the shipbuilders of that period.

His major work, *Architectura Navalis Mercatoria*, was published in 1768 as a series of drawings, supplemented by explanatory text contained in his *Treatise on Shipbuilding (Tractat om Skepps-Byggeriet)* in 1775.

In this latter work Chapman, like Bouguer, acknowledged the shipwright's practical skill in drawing on his own experience in seeking to build progressively better ships, but he also observed how new faults appeared as old ones were eliminated. This he attributed to a lack of theoretical knowledge. 'One discovers,' he wrote, 'that better or worse ships are built by chance, rather than by positive intention, and in consequence thereof, as long as another basis of knowledge is not available other than experiment and experience, ships are not able to attain perfection beyond that which they now have. It is, for that sake, necessary to find out what it is that will bring that knowledge closer to perfection'.[9] Chapman's *Treatise* clearly and systematically defined technical concepts for the shipbuilder, with useable formulae and a simple design method illustrating how many features previously determined by trial and error could be calculated on the drawing board. But even Chapman's audience was limited for although his *Treatise* was translated into French in 1779, an English edition did not appear until 1820, by which time the transformation of ships and shipping was already under way.

## Frederik Henrik af Chapman (1721–1808)

Frederik Henrik af Chapman, a Swedish scientist and shipbuilder.

Chapman was born on 9 September 1721 at the Royal Dockyards of Gothenburg. His mother, Susanna Colson, was the daughter of a London shipwright and his father, Thomas Chapman, was an English naval officer who had joined the Swedish Navy in 1716.

Chapman showed an early talent for shipbuilding, although he lacked the specialised mathematical knowledge needed for the stability and design of a vessel, something he would later study under Palmqvist and Thomas Simpson. He spent time working in private and state shipyards, following time at sea including working as a ship's carpenter in London. This would later provide the basis for many of the plans and drawings featured in his work, *Architectura Navalis Mercatoria*, published in 1768. When he returned to Sweden, he and a Swedish merchant, Bagge, became joint proprietors of a small shipyard.

At 36, Chapman was appointed Assistant Shipwright at the Royal Dockyards in Karlskrona, one of Sweden's largest naval bases.

He drew up blueprints for a dockyard with ventilated sail storage and advanced dock pumps, making it one of Scandinavia's most efficient ports, plans he implemented when he was made Chief Shipwright. As Assistant Shipwright, he designed a fleet of new frigates for use in shallow waters, in collaboration with Augustin Ehrensvärd, the commander of the archipelago fleet, to defend what is now the Finnish coast.

Chapman was made a member of the Board of the Admiralty in 1776, he believed the decline in Swedish maritime interests was because the Swedish Navy were in need of new ships, which were less costly to maintain and repair. In opposition to the traditional shipbuilders, the pioneers, backed by Chapman and General Admiral Henrik af Trolle, proposed experimental scientific designs to improve the efficiency of Swedish ships.

In 1781, Chapman was made the head of the dockyards at Karlskrona. At the base, Chapman continued to produce new, innovative ships and machinery.

Frederik died on 19 August 1808, aged 87.

The elementary state of naval architecture and the conservatism of shipbuilders should not obscure the fact that innovation did occur in ships during the eighteenth century. The needs of privateers and slavers in the southern colonies of North America produced the fast sleek schooner with a small crew, widely copied in Europe. English shipwrights adopted the Dutch trend for ships designed to sail with fewer crew, thus increasing the ratio of cargo to crew, diminishing costs and increasing profits.

Another initiative intended to cut costs led to the development of the two-masted brigantine, a smaller ship less expensive to build and crew, which became popular on many ocean routes. The design of rigs was improved and, thanks to the Royal Navy, by the early eighteenth century the wheel had been adopted for steering in preference to the tiller in many English vessels. In France, the wheel was officially adopted in 1709 and ten years later it was in use in Venice. The Royal Navy was also behind the push to develop the first successful chronometer, enabling the accurate measurement of longitude (distance east and west). Pioneered by John Harrison, official acceptance and payment of the prize for his invention in the face of establishment intransigence took decades, finally coming from the Board of Longitude in 1773. However, it was not until the mid-nineteenth century that the chronometer became widely available to seafarers at a reasonable price. The result of all of this cumulative change was faster, safer ships with better handling and smaller crews. In addition, masters gained expertise from plying the same routes regularly, helped by better shipping information, improved charts and safer navigation through the knowledge of longitude.

As for steam power, few foresaw its revolutionary impact. Applied to the ship, the locomotive or the factory, steam power proved to be the supreme technical innovation of the day. The technological supremacy achieved by Britain by the early nineteenth century rested not on steam alone but on countless other advances, large and small, that flowed from it.

The phenomenon of what has become known as the Industrial Revolution steadily but dramatically transformed the country in a process that can still be seen driving economies in countries like Brazil, China and India today. It owed much to innumerable inventive entrepreneurs driven by curiosity and determination but also to those who took up and applied their inventions with often far-reaching economic and social consequences. Over time these new technologies would combine to produce bigger ships, shorter voyage times, better communications and improved ways of carrying an ever more diverse range of cargoes as shipping played a central role in encouraging economic development and shrinking the globe.

## Gabriel Snodgrass (fl. 1759–1796)

Gabriel Snodgrass was an 18th-century naval architect and ship surveyor for the Honourable East India Company. Working as a company shipwright in Bengal, he returned to the UK in 1757 when appointed Chief Surveyor to the HEIC. Considered one of its most experienced surveyors, he helped build and repair 989 ships, of which only one foundered while he was in service. His revolutionary attitude to construction ensured that timber was used economically when scarce during times of war, and he increased a ship's lifecycle by promoting the use of stiffening in older ships, by installing diagonal braces in the transverse plane and doubling with three-inch oak planking to increase strength. By 1805, 33 warships had been strengthened in this way – 22 line-of-battle ships and 11 frigates. Snodgrass' revolutionary attitude was also evident in his introduction of the use of iron for knees, riders and braces to the ships of the HEIC from the 1780s and his support for the use of covered building slips.

## End Notes


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[2] C A Bayly, *The Birth of the Modern World, 1780-1914* (Oxford, 2004) p19

[3] William Bernstein, *A Splendid Exchange, How Trade Shaped The World* (London, 2009) p199

[4] Henry Martyn, *Considerations on the East India Trade* (London, 1701) p37, photographic reproduction in J R McCulloch, *Early English Tracts on Commerce* (Cambridge, 1970) as cited in William Bernstein, *A Splendid Exchange, How Trade Shaped the World* (London, 2009) p245

[5] P Mathias, *The First Industrial Nation, The Economic History of Britain 1700–1914* (Abingdon, 2001) p16

[6] Sir Westcott Abell, *The Shipwright's Trade* (Cambridge, 1948) p55

[7] W F Stoot, 'Ideas and Personalities in the Development of Naval Architecture', *Transactions of the Institution of Naval Architects* (hereafter *Trans INA*), 100 (London, 1959) p215

[8] Pierre Bouguer, *Traité du Navire* (Paris, 1746) as cited in W F Stoot, 'Ideas and Personalities in the Development of Naval Architecture', *Trans INA*, 101 (London, 1959) p217

[9] F H Chapman, *Tractat Om Skepps-Byggeriet* (Stockholm, 1775) as cited in Daniel G Harris, *F H Chapman, The First Naval Architect and His Work* (London, 1989) pp82–83

# 1760-1850

# 2 New marine technologies – iron and steam

The steamship characteristic of the nineteenth century was the product of the synthesis of two separate technologies themselves rooted in the nascent industrialisation of the Western world – the steam engine and the industrial production of iron. The genesis and early development of these new marine technologies was helped by pioneers sharing knowledge and information, the harnessing of new skills in engineering, the protection derived from state subsidies on early long-distance routes and operators convinced that investment in iron and steam was in their own commercial interest. But the steamship was still in its infancy, vastly outnumbered by the sailing ship, which continued to develop in parallel. As far as trade was concerned, western exploration, coupled with technological innovation, including the development of bigger, better ships, had already begun the process of globalisation.

This came about largely through western European incursions into other parts of the world, particularly the Americas, as well as the opening up of new routes to Asia around Africa. The world had already become a smaller place, although the exchange of peoples was limited, and the scale of international trade was still small. It has been calculated that there was little change in the per capita global gross domestic product (GDP) of around $400 a head until 1800. However, in trading terms the foundations had been laid that would facilitate the massive transformation consequent upon the arrival of industrialisation. By 1800, per capita GDP passed $700, and would increase steadily thereafter. The export of goods on a growing scale was fundamental to this shift and the new marine technologies played an integral role in the expansion of world trade.

# James Watt (1736–1819)

James Watt was a mechanical engineer and Scottish inventor credited with building the first modernised steam engine. Watt's invention was one of the catalysts for the Industrial Revolution.

Watt was born on 19 January 1736 in Greenock. His father, James, was a contractor, shipowner and shipwright. As a child, one of his hobbies was constructing toys with his own toolkit. It was expected that Watt would inherit his father's business. After numerous commercial disasters, his father's business declined greatly, as did his health.

As a teenager, Watt favoured mathematics and engineering. He went to London to study mathematical instruments and then returned to Scotland to set up his own business. Although Watt was more than capable of building instruments, he had not served the requisite seven years' apprenticeship and his application to the Glasgow Guild of Hammermen was rejected.

Watt befriended John Robison, a physicist and mathematician. In 1763, Robison and the University asked Watt if he could repair one of their Newcomen engines. Watt realised that it could be greatly improved and set out to develop a brand new, more efficient engine.

Watts's extensive research led to his theory based upon latent heat and he was able to increase the power of the machine's steam engine fivefold. Watt was unaware Joseph Black had discovered this theory years before. Watt and Black became friends and frequently discussed their research.

In October 1765, Watt imagined a completely separate chamber in a steam engine, which would condense the steam isolated from the piston, maintaining the temperature of the cylinder at the same temperature as the injected steam, creating a jacket of steam. By condensing the steam, there would be no need for a cooling or reheating process, which would make the engine faster and more fuel efficient. Black introduced Watt to John Roebuck, an inventor and industrialist. Roebuck agreed to finance Watt on the condition that he was given two-thirds ownership of Watt's machine. Watt refused, and self-funded the project, working as a surveyor and civil engineer over several years.

Although Watt and Roebuck displayed a healthy partnership, their differing opinions led to a split. Roebuck went bankrupt, losing all his steam patents, which were bought by Matthew Boulton, owner of the Soho foundry. He and Watt entered a mutual working relationship; allowing Watt access to Britain's most experienced and efficient ironworkers. Watt and Boulton's partnership would last for the next 25 years. Together, they would travel the country selling their steam engine design to miners and other industrialists, it was a popular engine as it was far more fuel efficient that its rivals.

Boulton suggested in 1781 that Watt design other applications for his engines, modifying them so that they could grind or weave. This would allow the partnership to expand into new profitable markets.

By 1800, they had both retired and their sons, Matthew Robinson Boulton, and James Watt Jr. took over the business. Watt continued to invent new instruments, such as copying machines.

He died on 25 August 1819 at the age of 83 at his estate in Handsworth, Staffordshire.

The genius of James Watt's first practical steam engine in 1765 lay in the condenser which revolutionised the efficiency of Newcomen's earlier engine. In 1781 Watt patented the improved rotary steam engine. Given previous attempts to harness steam for marine purposes, this had obvious potential for steam navigation, yet he proved too cautious and too protective of his patent rights to adapt the technology for shipping. His patent did not expire until 1800, delaying the wider diffusion of steam power on both land and sea. In October 1788 the first steam-powered passenger voyage took place on the Dalwinston Loch, when five passengers were carried across the loch in a catamaran driven by a steam engine built by the engineer William Symington and financed by the wealthy Scottish banker Patrick Miller. Yet Watt refused Miller's invitation to explore the potential of steam navigation together. The exploitation of steam for shipping would be left to more entrepreneurial pioneers.

One of the keys to unlocking the potential of steam navigation was harnessing the skills of new industries. The way in which shipbuilding and engineering would converge was foreshadowed by the experiments of an American, James Rumsey. When he sailed a steam-powered model boat on the Potomac at Richmond, Virginia, in 1784, the engine cylinders were cast in a Maryland iron foundry while other parts came from a Fredericktown coppersmith and a Baltimore brass foundry. When another American, John Fitch, built a small steamboat to demonstrate on the Delaware in 1786, he employed a mechanic to help him. Four years later Fitch built another steamboat, which carried cargo and passengers between Philadelphia and Bordentown.

Another factor that helped to accelerate early developments was the early interchange of ideas and information. Rumsey and Fitch knew each other as rivals, while Robert Fulton, another American, knew the work of both Rumsey and Fitch. He met Rumsey when both men were in England, Rumsey building an experimental steam vessel which was trialled on the Thames in 1793. Fitch had moved to France, and it was while he was on a visit to London in the early 1790s that Fulton was 'lent' the plans Fitch had left in the care of the American Consul in Lorient. Fulton also sought out the Scottish steam engineer William Symington, who had taken advantage of the expiry of Watt's patent to patent his own direct-acting steam engine in 1801. That summer Symington happily shared his knowledge with Fulton, even taking him along the Forth and Clyde Canal on his steam-driven vessel. Symington would justifiably claim that 'I am the first individual who ever effectually applied the power of the steam-engine to the propelling of vessels'.[1] His engine powered the stern-wheel vessel *Charlotte Dundas*, which in 1803 successfully towed two barges some 18 miles along the Forth and Clyde Canal. But the capital costs of developing the vessel were not fully met and the canal company's concern over erosion of the canal's banks meant that she was laid up. Fulton also knew another Scottish engineer, Henry Bell, who had worked for the yard that built the *Charlotte Dundas*, and Bell supplied Fulton with details of other vessels on which Symington had worked. Fulton's experience shows the ease with which it was possible to diffuse knowledge in the world of the late eighteenth and early nineteenth century, which was smaller than we perhaps imagine from our twenty-first-century standpoint.

Commercial success evaded Rumsey, Fitch and Symington. They all failed to persuade possible investors that the commercial potential of steam navigation outweighed the risk of financing its early development. Fulton was luckier. Robert Livingston, whom Fulton had met when Livingston was American Ambassador to France, was so convinced that steam navigation was a viable business proposition that he had been granted the monopoly for operating steamboats on all the waters in New York State. His venture stalled when Boulton & Watt refused to supply him with steam engines. Instead, he turned to Fulton, and together the two men developed a paddle steamer which they trialled on the River Seine in 1803. Since Watt's patent had expired, the two men were able to adapt a Boulton & Watt condensing steam engine. Back in the USA, they commissioned a vessel from a local shipbuilder using parts shipped over from England, helping to diffuse the early elements of the new technology.

# Robert Fulton (1765–1815)

Robert Fulton was an engineer and inventor widely regarded as the father of maritime steam research. Fulton also showed an interest in the canals of England and the US, and wrote a book on the subject, *A Treatise on the Improvement of Canal Navigation (1796)*.

He was born in on a farm in Pennsylvania in 1765. He was educated at a Quaker school. In his twenties he published a pamphlet about canals and invented a dredging machine.

Fulton met James Rumsey who built and sailed his very own steamboat along the Potomac River. By 1793, Fulton designed blueprints for steam-powered vessels in both the US and Great Britain. During this period, he struck up a friendship with Francis Egerton, the Duke of Bridgewater, who was constructing Britain's first man-made canal, which was being used for steam tug trials. Within three years, Fulton and Egerton were constructing the *Bonaparte* in the Duke's own timber yard, but due to increasing costs, the construction was abandoned.

In 1797, Fulton went to France to begin experimenting on torpedoes, and designed the *Nautilus*, the world's first functioning submarine. His trials proved the submarine could submerge to a depth of 25 feet of water for 17 minutes. After initial rejection from the French government, *Nautilus* was built at the Perrier shipyard in Rouen, and sailed on the Seine in July 1800.

In 1806, Fulton returned to America and married Harriet Livingston, the niece of his friend Robert. Their bond as strong as ever, Fulton and Livingston continued to develop steamboats.

By 1807, the partnership produced the *North River Steamboat* – a 1,210-ton, 142-foot vessel propelled by a paddle-wheel. Many criticised the construction of the ship, calling it 'Fulton's Folly'. When the ship successfully sailed, its detractors recognised such an achievement, and Fulton was vindicated. It was put into active service, between New York City and the state capital of Albany. The vessel made the 150-mile trip in 32 hours. Soon after, Fulton was made the Governor of New York and a member of the Erie Canal Commission, the body formed to build a vital canal link between New York and Lake Erie.

Fulton's last project involved designing the world's first steam-driven steamboat for the United States Navy in preparation for the war of 1812. The ship was named *Demologos*, but due to Fulton's death prior to completion, the ship was renamed *Fulton*.

Fulton's swan song came in the form of the *New Orleans*, a steamboat that navigated the uncharted waters of the Ohio and Mississippi rivers, which had only been under US jurisdiction for 10 years. The *New Orleans* was a joint venture between Fulton, Livingston and Nicholas Roosevelt, the inventor of vertical paddle wheels for steamboats. Once again, Fulton displayed his ingenuity by designing the first ship that could reverse, a simple premise that changed the landscape of America's maritime industry for years to come.

Fulton contracted pneumonia, several months later, at the age of 49, he succumbed to the disease, dying in New York on 24 February 1815.

Like Rumsey, Fitch and Symington, Fulton and Livingston also employed the skills of the infant engineering industry to overcome the challenges involved in constructing gearing and paddle-wheels. The combination of Fulton's engineering genius and Livingston's financial acumen produced a triumph. On 17 August 1807, the paddle steamer *Clermont* set off on her maiden voyage up the Hudson River from New York to Albany and back. Thousands of spectators crowded the river bank, convinced they were about to witness an abject failure. Instead they were captivated by the vessel's speed and stability, and their jeers turned into cheers. Speed, stability and the advantage steam offered in making it possible for a ship to adhere for the first time to a regular timetable made the *Clermont* a commercial success. The phenomenon of the steamship had arrived and on concluding the voyage Fulton could write that 'The power of propelling boats by steam is now fully proved'.[2]

The following year John Stevens' steamer *Phoenix* became the first steamship to venture into the open sea on a lengthy voyage, sailing from Hoboken to Philadelphia, under the command of Captain Moses Rogers. Four years earlier Stevens had built and then abandoned an elementary screw-propelled steamship on the grounds that existing engines were not up to the task.

Following the success of the *Clermont*, Fulton wrote to Henry Bell to let him know he had used the information Bell had given him to help build his own steamboat and set up a successful commercial service. This inspired Bell to follow suit and he commissioned a paddle steamer from local shipbuilders John and Charles Wood in Port Glasgow, with an engine built by John Robertson and a boiler made by David Napier. The *Comet* began carrying guests along the Clyde from Glasgow to Bell's hotel in Helensburgh in August 1812, inaugurating the first commercial steamship service in Europe.

Invention had become innovation and the efforts of pioneers like Fulton, Symington and Bell, who brought together the skills of both shipbuilders and engineers, encouraged the wider commercial adoption of the steamship. Fulton himself was convinced that steam navigation had worldwide potential, drawing up plans for its introduction in England, Russia and India. Within a decade of his Hudson River service, steamers were plying inland waters all over the world, on the Thames and the Elbe, the St Lawrence and the Rhine, the Swedish lakes and the Brahmaputra. By far the greatest number operated on the lakes and rivers of North America; historian Basil Greenhill noted that in 1819 more than a hundred were steaming the rivers of the western USA, compared with 43 across the entire British Empire.

Other entrepreneurs began testing the commercial potential of the steamship on more challenging coastal and short-sea routes. In 1815 George Dodd, a London engineer, made the first European sea-going voyage under steam, when the paddle steamer *Duke of Argyle* steamed down the British coastline from Greenock via Portsmouth to London, from where she began a regular scheduled service between London and Margate. Three years later David Napier, who had supplied the *Comet*'s boiler, commissioned his own steamship, the 90 ton, 30 horsepower (hp) paddle steamer *Rob Roy*, opening a regular service across the Irish Sea from Greenock to Belfast. The term nominal horsepower (nhp) was used to indicate the capability of early reciprocating steam engines. It was based on dimensions rather than performance and did not indicate the actual power developed by the engine. Napier had been experimenting with models in a tank, which led him to appreciate how an improved hull design could help to curb fuel consumption; the *Rob Roy* was therefore designed with finer bows, an innovation arousing some criticism from his more conservative peers. In 1820 Napier transferred the vessel to the packet service across the English Channel.

# Colonel John Stevens (1749–1838)

Colonel John Stevens was an American engineer and inventor who successfully produced and tested the world's first screw-propelled steam vessels.

He was born on 26 June 1749 in Perth Amboy, New Jersey. His family had settled in the US in 1699, where they were established as wealthy merchant shipowners.

Stevens graduated from King's College (today Columbia University) in May 1768. Eight years later, he was made a Captain in George Washington's army during the American Revolution of 1775–1783; he was later promoted to Colonel. After the war, he became a treasurer of New Jersey, and enabled the purchase of his estate at Castle Point in Hoboken, New Jersey. Keen to protect his inventions he petitioned the US Congress with an outline for a patent law, which became the US Patent Law of 1790. In 1802, Stevens built a screw-driven steamboat, the first of its kind.

Stevens' greatest achievement would come in 1804, when *Little Juliana* was built, named after Steven's first daughter, Elizabeth Juliana. The boat, just 25 feet long, was used to demonstrate the power of the steam-powered screw propeller, an idea that Stevens had proposed and designed. The vessel was equipped with a high-pressure steam boiler, twin screws and novel engine. *Little Juliana* succeeded in crossing the Hudson River and paved the way for steam-powered propulsion systems. Two years later, Stevens and his son Robert built the *Phoenix*, a steamboat that successfully navigated 70 nautical miles from Hoboken to Philadelphia. As Robert Fulton, the inventor of the world's first commercially profitable steamboat, held a steamboat monopoly around America's north-eastern waterways, *Phoenix* had to cross the open ocean; the first known instance of a steamship managing to do so efficiently.

Stevens started to develop a steam powered ferry service to run between New York City and Hoboken. He achieved his goal in October 1811 when *Juliana,* the world's first steam-driven vessel was put into service.

Because of Stevens' work, he and a number of other promising engineers were granted the first railroad charter in US history in 1815. He continued to work in the locomotive industry, where he produced a steam train capable of pulling numerous passenger cars at his estate in Hoboken in 1825.

Stevens died on 6 March 1838, aged 89. Today, his estate survives as part of the Steven's Institute of Technology, opened in 1870. In April 2014, the Institute revealed that it had commissioned a number of its students to build a replica of *Little Juliana*. The Institute hopes that the vessel will participate in several exhibitions around the New York and New Jersey area, as a testament to Steven's ingenuity.

The first steamer in the Mediterranean, the *Ferdinando Primo*, entered service in 1818 while the paddle steamer *Stockholm* began the first steamship service between Sweden and Finland in 1821. In the coastal trades and on short sea runs the number of steamships was proliferating. By 1824 the *Steamboat Companion* listed 24 steamboats operating on the River Clyde, several of which were sailing regularly to Belfast and Liverpool.

The new technology worked happily alongside the old. In 1817 the vessel *Tug* was built in Scotland to help sailing ships on the Firth of Forth, giving her name to a new type of ship. The tug quickly proved invaluable in assisting sailing ships upriver and within the new docks being built across Europe as well as towing them into the wind in the open sea. Perhaps the most famous image of this combination is Turner's *The Fighting Temeraire* of 1839, which evocatively depicts the ascendancy of the new order over the old, steam over sail.

With the huge advantage of operating regardless of wind and tide, wooden paddle steamers were excellent for the speedy carriage of passengers and valuable low-volume cargo, such as perishable goods or mail, over relatively short distances to a regular timetable. Operators had to calculate the commercial viability of these new services by setting the premium prices they commanded against the high capital costs, operating costs and limited cargo space of the early steamships.

The early steamers offered greater regularity than a sailing ship but were no faster, as the low thermal efficiency of their engines initially prevented them from challenging the sailing ship in certain trades. High-value cargo such as mail and passengers were easily accommodated, but reasonable freight rates on bulk cargoes like grain and timber were not achievable due to the amount of space taken up by fuel. By 1800, Watt's improvements had increased the thermal efficiency of a full-size Newcomen steam engine by about a factor of four, but the overall thermal efficiency was still low. Fred Walker, a naval architect, notes that thermal efficiency was just one per cent on the earliest steamships but rose to around ten per cent by the 1890s. Even today, the thermal efficiency of engines in large ships is still only around 50 per cent.

The elementary nature of the technology and the continuing widespread use of timber for ships' hulls constrained the size of these early vessels but fortuitously this gave them the ability to operate from almost every port without the expense of additional infrastructure. As a consequence this new technology was soon in evidence in many ports around the British coast even though overall steamship numbers were still very small by comparison with the number of sailing ships. By 1829, steamships could be seen in 37 UK ports, with significant numbers in the leading ports, and by 1834, the year when LR was reconstituted as Lloyd's Register of British and Foreign Shipping, there were regular commercial steamboat services in more than 70 UK ports. The number of steamships rose from 11 vessels of an aggregate 542 tons in 1811 to 900 vessels totalling 114,000 tons in 1844. They were built in as many as 70 different locations, made possible because of their small scale. In the UK the new technology was being widely shared across many different shipbuilders, engine builders and shipowners.

That other great agent of change, the steam locomotive, was preceded by the steamship, which spread more rapidly. The international speed and breadth of its diffusion was unique. In Denmark, the first paddle steamer, the Scottish-built *Caledonia*, appeared in 1819, the same year in which the first steamboat was built in India. Steamships from the Netherlands began operating short sea voyages in 1823 under the Nederlandsche Stoomboot Maatschappij. The first steamer to trade along the Pacific coast of South America was the *Telica* in 1825, operated without success (partly because of the scarcity of fuel) by a young Spaniard, who in despair fired his pistol into a barrel of gunpowder, blowing up the vessel and killing himself and all the crew bar one.

# William Symington (1764–1829)

William Symington was a Scottish engineer and inventor who built the world's first practical steamboat, the *Charlotte Dundas*. Symington was born in 1764 in Lanarkshire, his father worked as an engineer. He received an excellent education and decided to follow his father and become an engineer. Aged 21, Symington helped his brother to build a functioning steam engine at a lead mine in Dumfriesshire to drain the mine. Using Boulton & Watt's specifications, Symington and his brother built the second steam engine produced on Scottish soil. His skills impressed the manager of the mine, Gilbert Meason, who enrolled him into the University of Edinburgh in 1786.

With Meason's backing, Symington created an improved atmospheric engine to replace Boulton & Watt's engine, patented in 1787. Under a second piston within the engine, steam was condensed, when the piston was pushed down, fresh steam entered the cylinder, and expelled the condensed steam.

As word of Symington's genius spread Patrick Miller, a banker from Dalswinton, Dumfries, approached him to modify his patented steam engine for use on a pleasure boat. Symington built the vessel and it was successfully in Dalswinton Loch on 14 October 1788; the pleasure boat reached 5 mph.

Following his success, Symington designed an even bigger steam engine, to be fitted to a 60-foot twin-hull paddle-boat on the Forth and Clyde Canal. During the vessel's trial on 2 December 1789, an increase in speed caused the paddle-wheels to fail. Miller, the project's patron, unhappy at the failure, sanctioned repairs and further successful trials were held.

After experimentation with other engines, Symington returned to working on steamboats, for the Forth and Clyde Canal Company. He designed an engine with a forward wheel attached to the hull, which was tested on the River Carron. The ship functioned poorly when on the canal, resulting in the company rejecting plans for a fleet. He attempted to improve the steamboat with the support of Lord Dundas, the company accepted the idea and supplied the engine. The *Charlotte Dundas*, named after Lord Dundas' daughter and the world's first practical steamboat, was tested on 4 January 1803, near the company's Glasgow offices. Symington held further trials in March. The ship not only powered herself but also towed two other vessels. Although there was a strong headwind, she travelled 18½ miles in 9½ hours, which was hailed as a great achievement.

Though the *Charlotte Dundas* was a success, the company believed the ship was an expensive failure and subsequently cut all ties to Symington. To make matters worse, one of Symington's key contracts, building tugboats for the Duke of Bridgwater, ended when the Duke died. The *Charlotte Dundas* was sold for £2 and 10 shillings in October 1803 and later became a dredger. After the *Charlotte Dundas* was retired from service, she was moored in a canal near Bainsford, where people ripped pieces of her timbers as souvenirs.

By 1829, Symington was ill. With spiralling debts and no money to pay for medicine, his health continued to decline until his death two years later. He was buried in St. Botolph's churchyard in Aldgate.

As the success of the steamship was confirmed by its spread from rivers and lakes to short sea voyages, so entrepreneurs dazzled by its potential and enticed by the possible profits sought to extend its sphere of operation even further. In 1819 the *Savannah* became the first steamship to cross the Atlantic. Although she used steam only intermittently as an auxiliary power source, her example contributed to several companies being launched in the early 1820s to promote steamship services between Europe and North America. Most of them failed, however, and interest was only revived following the crossing made mainly under steam by the *Royal William* in 1833. In 1838 the arrival of the wooden paddle steamer *Sirius* in New York marked the first Atlantic crossing to be made under continuous steam power. Her arrival, closely followed by Isambard Kingdom Brunel's *Great Western,* not only enthralled the public but also opened the door to transatlantic passenger, mail and cargo services operating to a fixed schedule. In 1839 three steamers entered the Atlantic service, the *Great Western*, the *British Queen* and the *Liverpool,* cutting the voyage time in half. The era of the ocean liner had begun.

However, such ambition exposed how previously tolerable weaknesses in the new technology turned into major hindrances to commercial viability. When the distance between two ports was short, the rapid rate at which the early steam engines gobbled fuel, their unreliability and the need to carry so much coal at the expense of cargo was not a major issue. Nor did the weakness of early boilers, which worked at an average pressure of just three pounds per square inch (psi) in the early 1830s, since the earliest boilers were safe only when operating at low pressure. On longer sea journeys, however, all these things mattered. In 1841 the engine builder Samuel Seaward pointed out how steamers were limited to voyages of no more than 20 days before fuel stocks had to be renewed.

The limitations of the paddle as a form of propulsion also became glaringly obvious. The rolling motion of heavy seas had the effect of raising one paddle out of the water while depressing the other, altering thrust and making steering a struggle. Power and efficiency were also impaired as the depth at which the paddles were immersed changed during a voyage when the reduction in fuel stocks made a vessel lighter. Paddles were also susceptible to damage in heavy weather. Sail therefore remained indispensable to the paddle steamer not only as an auxiliary form of propulsion but also to provide stability; yet reliance on sail exacerbated the vessel's weaknesses, making for poor sea-keeping qualities as well as difficulties to load and discharge, because of the unsatisfactory spacing of the masts determined by the position of the paddle wheels.

Given these challenges, it is not surprising that sustaining the extension of this infant technology on some long-distance voyages was possible only if the operators' costs were underwritten by the state. The first UK mail subsidy was awarded to the General Steam Navigation Company for the service from London to Rotterdam and Hamburg in 1834. In 1837 a UK government subsidy ensured the success of the mail contracts delivered by the Peninsular Steam Navigation Company (later to be known as P&O) running to Spain, Portugal and Gibraltar, which was followed in 1842 by the award of another heavily subsidised contract to the company to ship mail between Calcutta and Suez. Subsidies, in guaranteeing revenue over a fixed period, facilitated the first steamship fleets. When the British & North American Royal Mail Steam Packet Company (later Cunard Line) won the subsidised mail service contract between the UK and North America in 1840, state funding enabled Samuel Cunard to place orders for four steam vessels, supplemented by six more before the end of the decade. Similarly, American steamships were able to compete on this route from 1846 onwards only thanks to congressional subsidy.

As well as Cunard, the list of transatlantic steamship mail carriers subsidised by the state included the Ocean Steam Navigation Company, the Collins Line, the New York & Havre Steam Navigation Company, the Canadian Steam Navigation Company and the Allan Line. Unusually the service begun by the Hamburg-Amerika Linie (Hamburg-Amerikanische Packetfahrt-Actien-Gesellschaft HAPAG) in 1847 carried mail without subsidy, relying on that other mainstay of transatlantic steamship revenue, the passenger.

Many observers believed that the paddle steamer represented the acme of marine steam technology; it was destined for a long life, particularly in those roles for which it was best suited, such as tugs and passenger traffic. Despite the disadvantages of the paddle, technological development came only gradually and the transatlantic paddle steamer survived until Cunard's *Scotia* was withdrawn from service in 1875. She was, however, a massively different vessel from most of her predecessors, not only in terms of size – she was 3,871 grt (gross registered tons) – but also thanks to her iron hull.

By the mid-1800s wood technology was being stretched to the limits. Beam knees, braces and other stiffeners to reduce the strain upon the hull in the largest wooden ships became essential. Hardwood was becoming increasingly scarce as were the natural wooden crooks or 'grown knees' traditionally used for strengthening vessels. As a substitute, knees made from iron were used in substantial numbers by the French Navy by the mid-eighteenth century; an early example was found on the wreck of the French warship *Invincible* built in 1744 and lost off Portsmouth in 1758. Gabriel Snodgrass, Surveyor to the Honourable East India Company (HEIC), retrospectively fitted some of the Company's vessels with iron knees and from 1810 the Company's ships were newly built with them. Iron knees offered superior strength and compactness and their use spread to other builders, evident in their inclusion in the *Lloyd's Register of Ships* from 1814. The Royal Navy adopted the practice of retrospectively fitting iron knees to vessels strained by long periods enforcing the blockade during the Napoleonic War.

In 1811 the search for further ways of strengthening the largest wooden hulls led Robert Seppings, the British Master Shipwright, to insert diagonal cross frames, initially timber, and later iron. Ironically, since the Royal Navy did not acquire its first steamship until 1822, this innovation was instrumental in making wooden hulls sufficiently strong to carry steam engines and propeller shafts. There was a limit, however, to the stresses and strains that wooden steamships could endure as vessels became longer and engines and machinery heavier, which was effectively reached by the 1840s and epitomised by Brunel's *Great Western*. Sail-assisted and steam-driven, at nearly 252 feet long and 1,700 grt, she was one of the greatest ever sail-assisted wooden steamships.

The use of iron to construct the hull of the canal barge *Trial* by John Wilkinson in 1787 was an opportunistic rather than innovative decision, taken to overcome delays in the canal boatyards. More than 30 years would elapse before an inspired commercial decision took advantage of the industrial production of iron to create the first iron ship. In May 1819, the launch took place of the *Vulcan*, an iron horse-drawn passenger barge designed and built by Thomas Wilson. Destined to work on the Monklands Canal in Scotland, she was the world's first true iron ship. Built with small iron plates riveted to the frames, the *Vulcan* was, for one authority, 'the grandfather of all iron vessels to follow in the subsequent sixty years'.[3] This small vessel was the start of something big, hinting at the industrialisation of shipbuilding and its transformation into an organised engineering process, a development that quickened with the growing sophistication of the iron foundries.

# John Wilkinson (1728–1808)

John Wilkinson was an eighteenth-century industrialist who invented the world's first precision boring machine and was an innovator of cast iron manufacture during Britain's industrial revolution.

Wilkinson was born in Bridgefoot, Cumberland (now part of Cumbria), the son of an iron founder. Aged 17, he worked as an apprentice ironmonger in Liverpool. After five years, he became an independent ironmonger and briefly worked at his father's foundry until the late 1750s. When his father died in 1760, John assumed control of the works, but the majority of the responsibility fell on his older brother William.

In 1766, Wilkinson built the Bradley Works, in Staffordshire. This was arguably his most profitable venture, as he was able to experiment with substituting coke for raw coal in cast iron production. The factory included rolling mills, blast furnaces, potteries and brick works. Wilkinson's quality of iron prompted buyers to enquire about the construction of guns and cannons, and Wilkinson decided to begin producing them. In 1774, he decided to create his own method of producing high quality guns. The technique involved boring iron guns from a solid piece of cast iron by rotating the gun barrel rather than the boring bar. This process made the cannons much more accurate and less likely to explode from misfires.

Aside from his work with cast iron, Wilkinson also sold steam engine cylinders, which due to his boring methods were some of the finest in Britain. Boulton & Watt gave him the exclusive contract for producing the cylinders for their engines. Many attribute the expansion of the Boulton & Watt business to Wilkinson, as he encouraged them to provide their steam engines to a number of forges and driving mills. Following a dispute relating to Wilkinson selling engines that were not declared to Boulton & Watt, they parted ways. Boulton & Watt moved their factory to Stoke on Trent.

Wilkinson was one of the greatest supporters of the Iron Bridge, which crossed the Severn at Ironbridge Gorge in Shropshire. It was the first bridge of such a large scale to be built entirely out of cast iron. It still stands today, as part of a UNESCO World Heritage site.

By 1787, Wilkinson had finished the construction of the world's first iron barge – the *Trial*, which was constructed at the Broseley Works. This accomplishment is disputed, as the world's first complete iron barge was in fact the *Vulcan*, built 32 years after the *Trial*.

Nine years after the *Trial* was built, Wilkinson was becoming known as 'Iron-Mad Wilkinson' or 'Iron-Mad Willy', as he was producing one-eighth of Britain's cast iron. This work with iron continued into the 1790s, when he made numerous iron coffins, a giant iron obelisk to mark his grave, and funded the iron windows and pulpit at the Methodist church near his works in Bradley.

Wilkinson died aged 80 in July 1808 at Bradley. He was buried in an iron coffin with an iron obelisk.

As with the steam engine, new skills emerged for it was the smith rather than the carpenter who knew how to handle iron. As John Scott Russell, reflecting on the adoption of iron, wrote in 1864, 'The men who did know something of the qualities and properties of iron were quite another race, occupied in thinking of quite other things'.[4] But none of this would have occurred if iron had not proved superior to wood for hull construction. Iron plates yielded less weight and greater internal dimensions than wood for a similar sized vessel, making it possible to build much longer ships with greater cargo capacity that could travel faster with the same power and were easier to handle at sea. As the output of iron increased and the price dropped, such ships also became cheaper to build and maintain while their strength made them safer and more robust. More and more iron hulls were built and ships became ever larger. By 1837, one consulting naval engineer by the name of Bowman was designing 2,600-ton iron ships for the European & Australian Mail Company; he was also incorporating longitudinal or diagonal iron stringers for the wooden decks.

Like so many of the other major advances in ship technology, the adoption of the iron hull was gradual. As well as the time needed to cultivate the new skills for constructing iron hulls, there were a number of other hurdles to overcome. Corrosion and fouling were common problems. Eventually they would be solved by the use of better coatings and copper sheathing. A short-term solution was to combine an iron frame with wooden planking to which copper sheathing could be applied. An early example of this method of composite construction was the steamer *Assam* in 1839. Another problem was the disruption caused by the iron hull to the ship's magnetic compass. By 1838, the Admiralty had come up with a solution thanks largely to the work of mathematician and Astronomer Royal Sir George Biddell Airy, KCB, PRS. Using the iron steamer *Rainbow* for his experiments, Airy came up with a method of neutralising a ship's magnetism by positioning magnets and pieces of un-magnetised iron near to the compass.

As well as being initially more expensive than wood, iron was limited to small plate size and could be variable in quality, as wrought iron was inherently brittle. Iron shipbuilding was a new technology, and the new shipbuilders were finding their way with little advice to guide them, though they did gain experience from land-based engineers, especially boilermakers. All these reasons deterred the conservative shipping industry from adopting iron hulls.

By the early 1830s the use of iron for sea-going vessels was still novel as one writer indicated in the *Mechanics' Magazine*: 'Sheet-iron seems to me the substance to which we must come. It is found effective for canal boats; what then should be the objection to it for the sea? It will, probably, be found to form a more buoyant boat than oak, and for the resistance of a shock, I should imagine a sheet of malleable iron much more effective than timber'.[5]

It was only later in the 1830s that iron ships started to become more common as production increased, exceeding a million tons for the first time in 1837. Quality improved and prices dropped. To raise quality standards, quantitative testing had been introduced, which also resulted for the first time in the accumulation of scientific data on ships' structures. The introduction of a new system for measuring tonnage in 1836 also helped, as it provided for measurement to be based on cubic capacity. Although optional until 1854, after which the Moorsom System was applied, the Act influenced the design of longer, shallower hulls, capable of carrying just as much cargo but with much improved sailing and sea-keeping qualities. Prior to this, the older builders' measurement, based on the Tonnage Act of 1773, had emphasised breadth and length, resulting in narrow ships in an attempt to reduce tonnage. The paddle steamer *Sirius*, built at Millwall in 1837, was the first iron ship classed by LR: she appeared in the *Register Book* in 1838 with the notation A1 'Built of Iron', but without the term of years usually assigned to wooden vessels.

It was not until 1844 that LR first began to take a formal view on iron ships, when it was agreed that the grade A1 would be assigned to iron ships 'built under survey of the Society's Surveyors, and reported to be of good and substantial materials and with good workmanship'. The Society was not without expertise in the new material, having been assessing the quality of iron cables since 1808. In 1846 surveyors were also instructed to ensure all new chain cables had been tested and stamped as such.

By then, the iron hull had already been married to the steam engine as a solution to the stresses and strains on wooden hulls caused by heavy, vibrating machinery. The first sea-going iron steamship was the *Aaron Manby*. Prefabricated in sections at a Staffordshire ironworks and assembled on the Thames in 1821, she sailed from London to Le Havre in 1822. It was more than a decade later, however, before Tod & MacGregor on the Clyde opened the first purpose-built yard for iron steamships in 1834, with several more following up and down the UK by the early 1840s. The pace of change was gradual. In 1844 the *Register Book* listed just 18 iron vessels of an approximate aggregate 4,000 tons; even in 1853, out of 10,050 vessels just 62 were iron sailing vessels and only 133 were iron steamships or sailing ships fitted with small auxiliary steam engines. However, there were many more such vessels which were not classed with LR and so did not appear in the *Register Book*, mostly vessels used for service in sheltered water. When the sailing ship was still the main vehicle for the carriage of people and goods at sea, and the new technologies, expensive and often unreliable, were still in their infancy, most shipowners preferred to remain with what they knew.

Nevertheless, although overall numbers and tonnage were still small, the steamship had come to stay. Its commercial potential was winning more and more converts, particularly as teething troubles were overcome. By the 1830s the time was right to consider an alternative form of propulsion to the paddle. The obvious contender was the propeller. This was an age-old idea although the modern form can be traced back to the work of Robert Hooke in 1681, while the advent of the steam engine had stimulated innumerable proposals to harness one with the other. The French scientist Daniel Bernoulli first linked the propeller with the steam engine in 1752. In England Joseph Bramah designed a stern screw propeller in 1785 and William Lyttleton patented a screw propeller in 1794, while Charles Dallery, a French mechanical engineer, attempted to power a steamboat by screw on the Seine in 1803. The American John Stevens, after extensive trials with steam-driven propellers over the next few years, came to the conclusion that the existing form of steam engine was just not powerful enough for efficient screw propulsion. This did not prevent further experimentation. Among the vessels built by David Napier, one of the early innovators of steamships, was the *Rocket*, driven by two stern screw propellers.

Other experiments took place under Captain Delisle in France in 1823, though largely ignored at the time, and the Czech-Austrian inventor Josef Ressel, who successfully used his bronze Archimedes screw-type propeller on an adapted steam boat, the 48 grt *Civetta*, in 1829, reaching a speed of about six knots. In the latter year, gunsmith William McCririck and cabinet maker James Steadman experimented on the River Irvine and demonstrated a propeller as a replacement for paddles before the Royal Society in Edinburgh; in 1830 their idea was taken by Maxwell Dick to the Royal Society in London, but both Societies were discouraging in their comments.

Ignorance and uncertainty prejudiced many shipowners against the screw. Some were reluctant to do anything that pierced the hull below the waterline, others were convinced that motive power at the stern would hinder a vessel coming up into the wind. But a solution was coming ever closer and the practicality of the steam-driven screw propeller was finally proved in the late 1830s by John Ericsson, a Swedish engineer settled in England, and by the Englishman Francis Pettit Smith. Both men were granted patents in 1836, both found financial backing and both enjoyed success, although on different sides of the Atlantic.

Ericsson, backed by an interested US naval officer, Robert Stockton, built the screw steamer *Robert F Stockton*, which he demonstrated to the Admiralty on the Thames in 1837. But his propeller proved too complicated and the vessel underpowered. His efforts were dismissed on the grounds that the vessel would be difficult to steer. Nonetheless, the ship successfully crossed the Atlantic under sail in 1839, followed by Ericsson's invention being widely adopted not only for US merchant ships but also by the US Navy, leading one historian to claim that 'America led the world in the use of the screw on its Great Lakes'.[6] Pettit Smith eventually found the Admiralty more receptive, but only after a long fight.

Financed by the banker John Wright, he first built a prototype whose success led to the building of the full-scale vessel *Archimedes*, which sailed around the UK and to a number of overseas ports, showing off the commercial potential of the screw propeller. Launched in 1838, the vessel was demonstrated before the Admiralty on the Thames on 16 October 1839. She proved slower than the paddle steamer with which she competed, but her performance impressed the Admiralty who invited Smith to design several similar vessels. These developments accelerated the momentum towards the general acceptance of the screw propeller, thanks 'to the combination of inventors of drive and imagination with backers of substance, together forming technical/entrepreneurial teams'. Most importantly, the ideas of Pettit Smith were investigated by Brunel, who conducted his own trials and adopted the propeller for his second great ship, the *Great Britain*. Pettit Smith continued to develop his research resulting in a propeller whose pitch is only one or two per cent out of what we would have done today, even though in design terms it looked entirely different.

Between 1836 and 1852, 74 ideas for propellers were patented in the UK. This included the first patents for variable-pitch propellers, as thought was later given to adjusting the pitch of propellers mechanically (controllable or adjustable pitch) in order to maximise the efficiency of the propeller at different speeds and for various load conditions.

One example was Bennett Woodcroft's design for a propeller with adjustable blades, patented in 1844. But the majority of screw propellers designed and patented during this period were what may best be termed fixed-pitch, which has since proved a cheaper and more robust means of propulsion for larger vessels that normally operate at a standard speed such as large bulk carriers, container ships and tankers. Variable-pitch propellers are usually found on aircraft, tugs, cruise ships, ferries, dredgers, cargo vessels and fishing vessels. Given its future contribution towards ever larger ships and the growing economy of seaborne transportation, the advent of screw propulsion has been called 'one of the major steps in the progress of mankind'.[7]

Even so, the early iron screw-propelled steamship was still underpowered and partially reliant on sail. There remained a technological divide to bridge before the screw propeller was widely adopted. Engines capable of driving a screw effectively needed more steam and thus more fuel, requiring not only more powerful and more efficient marine steam engines but also effective direct-drive machinery or gearing to moderate propeller revolutions. These in turn required steam pressures higher than existing boilers were capable of delivering. The gradual evolution of steamship technology and its accompanying shortcomings continued to put off conservative shipowners from investing in iron steamers. Compared with the tried and tested sailing ship, the steamship was a much more expensive proposition both to build and to run; its technology was still unreliable and there were fears that precious and perishable cargoes might be tainted.

For some owners, it was only the advent of the iron screw steamer that tempted them to begin investing in steamships. The Bibby Line of Liverpool, for instance, first took a stake in a steamship in 1850, with the iron screw steamer *Rattler* heralding a major investment programme in the new technology, which was accompanied by a steady withdrawal from sailing ships. Others were happy to wait for the pioneers to overcome any teething problems, or to run sailing ships alongside steamers.

These technologies, steam and iron, paddle and screw, were still in their infancy in the first half of the nineteenth century. The steamship was seen as the marvel of the age rather than the norm. Many of the early steamships, such as the *Savannah,* were in reality steam-assisted sailing ships, and auxiliary sail-rigged steamers were still being built in the early twentieth century. It was the sailing ship that still crowded every port. In the UK, wooden hulls and sail propulsion accounted for some three-quarters of all tonnage in the 1850s. They continued to be the workhorse of the oceans, transporting everything from fine silks and spices to bulk grain and coal as well as men and horses for waging wars, operating along the coasts as well as across the oceans. Some sailing ships already specialised in particular cargoes.
The most common was the collier, busy shipping coal from the Tyne to the Thames. Sailing ships of shallow draught built for capacity were bringing copper ore from the Americas to South Wales in the early nineteenth century. One less well known type was the small, elegant and speedy fruit schooner, bringing fresh fruit from Spain to the Thames in round trips of less than three weeks from the 1820s into the 1870s.

As the most common type of sea-going vessel, the sailing ship continued to develop. In particular, various types of faster sailing ship began to appear during the first half of the nineteenth century. There was no single reason for the emergence of these vessels. One impetus for change was the Abolition of the Slave Trade Act, 1807, which outlawed slave trading in the British Colonies, as slave traders then produced sleeker hulls for faster ships to evade British patrols. War, too, was an impetus. Designed to break the blockade of the War of 1812 between the USA and the UK, the famous Baltimore clippers, with their length six times their beam, sharper lines, lighter rigging and mechanical capstans and winches, were not only faster but proved more economical, needing fewer crew.

The end of the HEIC's trading monopoly was another stimulus to change, as competition created a demand for faster ships. These were the Blackwall frigates, built on the Thames and elsewhere, of which the first was the *Seringapatam* in 1837, a final revision of an essentially old-fashioned design.

The new technologies did have an impact on the development of the sailing ship, and their influence was first seen on the transatlantic route where speed was a consideration. This route was dominated by fast American sailing packets almost until the middle of the nineteenth century. American sailing ships had begun the first regular commercial transatlantic services, beginning with the Black Ball Line's *James Monroe* in 1817. One Black Ball Line vessel made 116 round voyages in 29 years without any losses, carrying some 30,000 passengers from Europe to North America. These vessels increased steadily in size and by the 1830s many of them exceeded 600 tons or more. When the first transatlantic steamers appeared, the Americans responded by introducing a superior, faster, better-shaped sailing packet. Longer, sleeker vessels such as these owed their speed as much to their length as to any improvement in the hydrodynamic shape of their hulls. Their increasing length in turn owed much to Seppings' concept of longitudinal construction, stretching to the utmost the technical limitations of wood as a material for shipbuilding.

The fact that the American design was copied by the British for just one vessel, on the HEIC's China run in the 1830s, illustrated the conservatism of most English shipowners. In general there was a cautious approach to experimentation, with few radical departures from traditional designs; improvements were the result of skilled judgement on the part of the builder/designer, derived from their accumulated experience. Most UK shipbuilders were still turning out ships of familiar design and scale, hindered by the constraints of the tonnage laws and Navigation Acts.

It was the change in the tonnage laws in 1836 reducing the emphasis on small breadth that gave UK shipbuilders the opportunity to try something new. Ironically, it was actually the sailing ship that took advantage of a change that came about partly because the space taken up by the machinery in the new steamships necessitated a better way of representing a ship's tonnage. The raking Aberdeen bow was designed by Alexander Hall & Sons of Aberdeen in 1839 to make the most of the opportunity for increasing duty-free cargo space arising from the new rules.

These changes also appear to have stimulated LR to become more explicit in what it required of shipbuilders through its own *Rules*. The early *Rules* were elementary, referring only briefly to construction methods. This changed with the publication of the *Rules and Regulations for the Classification of Ships* in 1837, which set a precedent for standards of shipbuilding by including tables for the different types of wood used and the required scantlings (that is, the dimensions of the structural parts of a vessel).

Hall's design was widely copied for wooden and iron sailing ships and steamships in the UK and overseas, including the Netherlands, Denmark and Nova Scotia. Sleek and graceful, these clippers were not only easy on the eye but also speedy through the water. This was exemplified by the fast sailing ship *Swordfish*, built in 1845 by Joseph Cunard, brother of Samuel, in Nova Scotia, which completed the return voyage from Pernambuco to Liverpool in just 22 days, averaging almost 220 miles per day, although such speeds could not be guaranteed regularly. Freak high-speed runs for sailing ships made headlines, but were not the basis for a regular commercial service, where predictability of schedule was key to competitiveness and mail contracts.

As well as improved designs, the sailing ship was able to hold its own to some extent through the use of wind and current charts from 1848 onwards that shaved days off traditional sailing routes. As a result, the sailing ship remained untouchable on longer-distance routes with low-value bulk cargoes like coal or grain, where time to load and discharge was not so critical. American shipyards, such as Donald McKay of Boston, continued to build fast clipper ships, some of which achieved remarkable speeds that, when wind and current conditions were fortuitous, rivalled the steamers of the day. The American *Sovereign of the Seas* achieved a remarkable average of 18 miles an hour over 24 hours in the early 1850s, which is not so far off the typical speed of 18 to 25 knots maintained by containerships today.

## End Notes

[1] David Napier, *David Napier, Engineer, 1790-1869: An Autobiographical Sketch with Notes* (Glasgow, 1912) p101

[2] H W Dickinson, *Robert Fulton, Engineer and Artist* (London, 1913) pp213–218

[3] Denis Griffiths, Andrew Lambert and Fred Walker, *Brunel's Ships* (London, 1999) p56

[4] John Scott Russell, *A Modern System of Naval Architecture Volume 1* (London, 1865) as cited in David MacGregor, *Fast Sailing Ships, Their Design and Construction, 1775–1875* (Lymington, 1973) p142

[5] *Mechanics' Magazine* (London, 1832) as cited in McGregor, *Fast Sailing Ships* (Lymington, 1973) p26

[6] C Matschoss, *Great Engineers* (London, 1939) p212

[7] E C B Corlett, 'The Screw Propeller and Merchant Shipping 1840–65', in B Greenhill (ed.) *The Advent of Steam – The Merchant Steamship before 1900* (London, 1993) pp87–89

1760-1850

# 3 The innovators

The innovators of the new technologies were often outsiders, practical men from the emerging engineering profession equipped with the necessary skills, whose empirical approach reflected the limited development of naval architecture and marine engineering by the early nineteenth century. While the industry on the whole was conservative in its approach to change, the enthusiasts for the new technologies were eager to share ideas and information, and promote a more scientific approach. As for LR, it too recognised the need to meet the greater complexity of iron-hulled steam-driven ships, reflected in its research and introduction of new *Rules* as the century progressed.

Many of the early innovators came from outside the established shipping industry. They were empiricists rather than scientists, practical men rather than theorists. Yet in their empirical approach, the newcomers differed little from the traditional shipwrights they were replacing. Even in the naval dockyards of the UK, the world's leading maritime power, 'there was no scientific basis of naval design whatever at the beginning of the nineteenth century'. Without any guiding rules, every new ship was in essence an experimental design, unless a copy was being made of a captured foreign warship. In commercial shipyards, things were no more sophisticated; an observer watching a ship being built in a Sunderland yard in 1804 commented that 'the superstructure was greatly an affair of guess-work and eye-work'.[1]

It seems unlikely that any better techniques were involved in European or North American shipyards. In Europe, as we have seen, there may have been more determined attempts to develop a scientific approach to ship design, but by and large these were of little value, and any that were any good reached only a very limited audience. In fact, the work of these theorists tended to give science a bad name. David Steel, the author of an early work on naval architecture, observed that Continental proponents of naval architecture had achieved little practical success, while he rated the works of Fredrik af Chapman as of little value 'since they are not to be understood without a previous acquaintance with the higher branches of the mathematics, of which very little is known among our artists'.[2] Another author, John Fincham, in 1832 lamenting the state of naval architecture to the First Lord of the Admiralty, Sir James Graham, suggested that the subject thus far had relied too much upon theory and too little upon experimentation and observation.
He summed up the defects of the present state of knowledge, noting 'the various alterations that are constantly made in our ships from the first design, their continually falling short of what was intended in some of their essential qualities, and their being frequently found defective in some point not anticipated by their projectors'.[3] A third observer noted in 1835 how:

*[t]he man of science and the practical shipwright have long lamented that, in the theory of the art of shipbuilding, there are so few fixed and positive principles established by demonstration, or confirmed by practice; thus the artist being left to the exercise of his own opinion, in general resists theoretical propositions, however speciously formed, so hard has it ever been found to overcome habitual prejudices. The great neglect of the theory of shipbuilding is much to be deplored in a country like this, where the practical part is so well understood and executed.*[4]

When John Scott Russell first turned towards the study of hydrodynamics and naval architecture, the only work of use he could find was that of Chapman. As a university graduate, mathematics teacher and science lecturer, Scott Russell deplored the lack of applied science in ship design and shipbuilding, which he blamed for ignorance over determining the exact power needed for a given speed and for the widely held view that buoyancy was based on shape rather than bulk.

The new technologies demanded new skills. Ship designers and shipbuilders 'had to think equally in terms of wood and iron, of sail and steam'.[5] The infant engineering industry, blossoming in an age of industrialisation, was a prime source of talent, producing able, determined and curious engineers, eager to tackle the challenges of a field completely new to engineering itself. The hurdles they faced were enormous. Material resources were limited, as were the means of working such material. 'It was pure chance whether a nut would fit any bolt for which it had not been made, for screw threads had not then been standardised. Nor were there any standard gauges or micrometers, the skill of the workman using hand callipers and a foot rule being relied on to secure accuracy and fit.'[6]

As David Bell, the editor of a life of David Napier, one of the early innovators, wrote, 'The shipbuilder also was called on to furnish vessels of unfamiliar type, fit to withstand the weights and strains of heavy machinery, and the engineer had to undertake the construction of engines, boilers and propelling apparatus for which his previous engineering experience gave but little guidance'.[7] The marine engineer and shipbuilder began to make their mark as the traditional shipwright began to disappear.

Some of these innovators made a wider contribution, for they not only built engines and ships, they also owned and operated their own vessels. David Napier, regarded as one of the first to adopt marine engineering as a distinct profession, was the son of a foundry owner. David took over the family firm in his early twenties. He began making steam engines, including marine engines, before commissioning his first steamship, the *Rob Roy*, followed by several others he ran either from the River Clyde or across the English Channel. The *Rob Roy* was built by William Denny at Dumbarton on the north side of the Clyde. Denny, the founder of a famous dynasty of shipbuilders, had begun shipbuilding in 1814; among early vessels by William Denny and Archibald McLachlan, was the *Trinidad*, the first steamship to sail to the West Indies. In 1818, their wooden-hulled *Woodford* was the first paddle steamer operating in Caribbean waters.

David Napier's original Clydeside premises were taken over by his cousin Robert in 1823. Robert went one step further than David and began taking orders for complete vessels, sub-contracting the wooden hulls to local shipbuilders. He went on to supply Samuel Cunard with his first four steamers (*Britannia, Acadia, Columbia* and *Caledonia*) and began building ships on his own account at Govan in 1841. Part of Robert Napier's success was down to his shrewd judgement in employing his fellow Scot, David Elder. Elder had been apprenticed to his father as a millwright. He was a talented engine builder and the engines he designed and built for Robert Napier achieved a reputation for reliability, a virtue highly prized when many early engines regularly broke down.

William Fairbairn, another Scot, the son of a farmer, also began as a millwright. He set up a successful mill machinery business in Manchester, the heartland of the booming cotton industry, before diversifying into boilers for ships and railway locomotives. This led him and his partner into shipbuilding with their first paddle steamer, built in Manchester in 1830. Its success persuaded them to move to a more practical location at Millwall in 1834, where Fairbairn introduced iron shipbuilding to the River Thames.

The pioneers of the *Comet*, John and Charles Wood, came from a traditional shipbuilding background. As timber for shipbuilding became scarce and expensive in the UK, the brothers emigrated to Canada, setting up a shipyard close to the abundant forests in Quebec. Eventually they came back to Britain in 1811 and took over their father's yard at Port Glasgow. By 1818, they were experimenting with screw-driven vessels. The brothers recognised the growing complexity of shipbuilding and were unusual among their peers in demanding a more scientific approach. John Scott Russell later acknowledged how much he had learned from them about shipbuilding.

The empiricism behind almost all innovations in ship technology in the first half of the nineteenth century remained the industry's preferred approach for decades to come, understandable perhaps given the imperfect development of naval architecture and marine science. Despite the publication in 1834 of Lloyd's Register's *Rules for the Classification of Ships*, by 1850 shipbuilding in most commercial yards in the UK still relied on rule of thumb: 'Mixing empirical virtuosity in one field with appalling ignorance and backwardness in another, [commercial shipbuilders] were innocent of mathematics, averse to science and hostile to theory.' Another historian concluded that most commercial shipyards had little regard for the idea that formal education had anything of value to offer a shipyard apprentice; 'Imitation of established forms, rough calculations and rule-of-thumb methods continued to dominate practices in private yards until the 1880s'.[8]

# John Rennie (1761–1821)

John Rennie was a Scottish civil engineer with numerous docks, bridges and canals across the United Kingdom to his credit.

Rennie was born on 7 June 1761 to James, a farmer, and Jean. From a young age, he displayed a keen interest in mechanics, constructing detailed ship models, simple cogs and other mechanisms. In 1766, when his father died, John's elder brother, George, assumed control of the estate. He managed to keep the family's finances in good order, despite being only 16.

At school, Rennie took time off to visit a local workshop, owned by Andrew Meikle who had invented the threshing machine, and offered him an apprenticeship. At 14, Rennie continued his mathematics studies at Dunbar High School. After two years, Rennie returned to work with Meikle.

In 1779, Rennie formed his own company to handle the overflow from Meikle's business. Rennie's first commission was to build Know Mill in Phantassie, for his brother George. Word of Rennie's determination and professionalism spread through Scotland, prompting a surge in business. He designed mills and introduced cast iron pinions to his machinery, but then, realising that his expertise would soon be inadequate, he enrolled at Edinburgh University in November 1780 to study mathematics, chemistry and natural philosophy – and the bagpipes.

In 1783, Rennie took a tour of the UK visiting various works and bridges. He visited Boulton & Watt, and went to Lancaster, Liverpool and Manchester. It was on this trip that he decided to start designing bridges.

Hoping to further his engineering expertise, he accepted a job at Boulton & Watt's Birmingham factory, and started work on 19 September 1784. Rennie studied the machines, mechanisms and sustainability, but Watt, very protective of his inventions and business, tried to bind Rennie's work to his company.

Rennie refused to be bound to Boulton & Watt, and in November 1784, he moved to the Albion Flour Mills in London. There, he designed the millwork in its entirety and introduced mechanised methods to produce flour. The Albion Mill was also one of the first factories to utilise the steam engine. Unlike Watt, Rennie was transparent and open; admitting the public to view the Albion works, a move that Watt believed would ultimately ruin him.

Only a year later, he was appointed engineer for the 57 mile long Kennet and Avon Canal, which covered a range of challenging terrain. The canal was a success and highlighted his ingenuity. The same year, Rennie was given the responsibility of engineering two more canals, the 76 mile long Lancaster Canal, and the 33 mile Rochdale Canal.

He was commissioned by Wick Harbour authorities to improve the port; this would be Rennie's first ever such project. His work there improved efficiency and load times, causing the ports of Liverpool, Dublin, Leith, Portsmouth, Hull and Sheerness to enquire about his availability. Rennie built the London Docks and, with Ralph Walker, constructed the East India Docks. It was during the construction of Humber Dock, Hull where he used his steam dredging machine for the first time.

In 1809, Rennie was commissioned by the Strand Bridge Company to design a bridge over the River Thames, the first Waterloo Bridge, based on his work at Kelso. The bridge measured over 1,380 feet, and was built of Cornish granite. This achievement secured more work including Southwark Bridge and Old Vauxhall Bridge.

Rennie's first official build of a lighthouse was in 1821; his Holyhead Mail Pier lighthouse still stands today. In 1807, he was appointed Chief Engineer of Bell Rock Lighthouse and visited Robert Stevenson during construction. He continued to correspond with him over the structure and design, although Stevenson and Rennie's views differed. Rennie died in October 1821, from inflammation of the liver. He was buried in St Paul's Cathedral. Two of his sons, John and George, also became notable engineers.

The conservatism of many shipbuilders reflected the attitude of the owners for whom they worked. Most builders, taking into account the cargoes to be carried, the principal trades involved and the required speed of the vessel, usually deferred to the fashion of the day, for most owners needed immediate profitable employment for their ships and could not afford to experiment. Innovation they left to a more intrepid minority and it was only once they were convinced of the commercial potential of any new advance that they were prepared to adopt it. Technological change for its own sake was not a dictum to which they subscribed.

The industry's conservatism towards the value of education also extended to official circles. The Admiralty blew hot and cold on the value of a more scientific approach. The School of Naval Architecture in Portsmouth was founded in 1811 but was closed down in 1832 by Sir James Graham. The Admiralty was also unwilling to appoint former students to any other than minor posts and they often endured jealousy from dockyard foremen and shipwrights. A successor, the School of Mathematics and Naval Construction, flourished from 1848 until 1853, when it was closed by Graham on his return as First Lord of the Admiralty.

In British universities, engineering as a taught subject developed only slowly. Although several of the older English and Scottish universities had Chairs in Natural Philosophy, which preceded the development of modern science as a subject, engineering was almost entirely absent before 1850. There were exceptions, including an intermittently taught course at University College, London, from 1828, where a Chair in Engineering was created in 1841; the Engineering Department opened at King's College, London, in 1838; Glasgow University's Regius Professorship in Civil Engineering was founded in 1841, and the Regius Chair in Engineering at the University of Edinburgh in 1868.

However, there was a more positive spirit among the cheerleaders for a new approach. John Smeaton, the first engineer to describe himself as a 'Civil Engineer', a term devised to distinguish himself from the military engineers graduating from the Royal Military Academy at Woolwich, was one of the founding members of the Society of Civil Engineers in London in 1771, the first such society in the world. It was later renamed the Smeatonian Society of Civil Engineers. A Society for the Improvement of Naval Architecture (SINA) was formed in London in 1791 as a forum for the exchange of ideas and furtherance of knowledge. Although short-lived, the Society's experiments on resistance would inform the work of Fulton as well as Brunel and Scott Russell.

It was also influential in promoting the better education of naval architects even before the advent of steam and iron, playing a part in the foundation of the short-lived School of Naval Architecture. This too was influential, producing a clutch of talented naval architects. Three of the alumni, William Morgan, Augustin Creuze and Henry Chatfield, produced several volumes of *Papers on Naval Architecture* between 1828 and 1832. The lead given by this school and its successor would be emulated in other parts of the world, including the Annapolis Naval Academy in the USA, founded in 1845, and the Stettin Naval School in Prussia which flourished from 1830 until 1869. Most such institutions, however, did not appear until the second half of the century.

Another conduit of technical knowledge for the new shipbuilders and marine engineers was the *Mechanics' Magazine* founded in 1823, which featured contributions from leading practitioners such as Charles Seward, John Seaward, John Penn, and the brothers John and George Rennie. At a local level, the shipmasters' and shipowners' societies found in a number of ports also helped to spread information more widely. With steamboats being built in as many as 70 different locations it seems clear that, whether through observation, the technical press or shared experience, knowledge was already being extensively shared among those who were enthusiastic about the new technologies.

# Marc Isambard Brunel (1769–1849)

Marc Isambard Brunel was famed for his work on the Thames Tunnel and inventing the first successful tunnelling shield.

Marc was born on 25 April 1769 to Jean Charles Brunel and Marie Victoire in Normandy. Although his father intended him to become a priest, Marc also learned carpentry and technical design. He later went to live with a family friend in Rouen who educated him in naval architecture. He joined the French naval cadets at age 19, where he would serve for six years.

In January 1792, he returned to Rouen, and met Sophia Kingdom, his future wife. Soon the French Revolution was rampant. Marc fled to New York where, following a series of projects spanning three years, he was made Chief Engineer of New York City.

In 1798, he discovered that the British Royal Navy was having difficulty in producing the hundreds of thousands of pulleys required to control the ropes attached to ships' sails. Without sufficient blocks, the Royal Navy would be without hundreds of ships. Brunel began to develop a machine that could mass-produce the blocks; in February 1799, he sailed for England, to present his machine to the Admiralty. When he arrived in England, he was reunited with Sophia and the couple married on 1 November 1799. They had three children, Sophia and Emma, and a son Isambard.

In seeking a factory to make his pulley block machine, Marc approached Samuel Bentham, a prominent English engineer and naval architect, and the Inspector General of Naval Works. They formed a successful partnership and by 1808, were making over 130,000 pulley blocks a year.

In 1818, Brunel patented a tunnelling shield, to build the Thames Tunnel. Construction had begun in 1805 when the Thames Archway Company attempted to tunnel from Rotherhithe to Wapping, but deaths and delays caused its abandonment after only 1,000 feet had been completed. Brunel's tunnelling shield was made of cast iron and had separate mining compartments. Bricklayers would line the surface of the tunnel with bricks, after it was driven forward with jacks. His machine would later become the basis for the London Underground's tunnelling network.

At the beginning of 1821, Brunel had fallen into debt and, along with his family, was imprisoned. Brunel spent a total of 88 days there, eventually the British government agreed a £5,000 grant to clear Brunel's debts.

Brunel's pleas for funding for his tunnel-boring machine were answered in February 1824, when a meeting was held and the Thames Tunnel Company was formed. The Thames Tunnel was the first project in which Marc's son Isambard joined him.

Work began on the tunnel in February 1825, with a 50-foot vertical shaft dug on the Rotherhithe bank. Throughout the build, the tunnel was delayed by flooding and financial problems. On 12 January 1828, it suffered one of its worst floods, killing six men and almost claiming the life of Isambard, who was found unconscious in the tunnel by a nearby contractor. The tunnel was sealed in August 1828 due to a lack of funds but reopened seven years later after new funding was found.

Aged 72, Marc received a knighthood, in November 1842 he had a severe stroke that partially paralysed the right side of his body.

The tunnel was opened to the public on 25 March 1843, 18 years after construction had begun. For the majority of the project, Isambard had assumed control due to his father's declining health. Within a year of the tunnel's opening, 1 million people had visited. Although the tunnel had originally intended to be used by horse-drawn carriages, it was restricted to pedestrians.

On the 12 December 1849, Marc Brunel died, aged 80, he was buried at Kensal Green Cemetery, London.

# Isambard Kingdom Brunel (1806–1859)

Isambard Kingdom Brunel was born on 9 April 1806 in Portsmouth. From an early age, Isambard displayed an ability to understand complex subjects. By the age of four, he had learnt how to hone his drawing skills and observations; four years later, he learned Euclidean geometry and was fluent in French. At age eight, Isambard was at boarding school in Hove, where he received a classical education.

By this time, he also had a basic understanding of engineering. One of his father's favourite hobbies was taking Isambard on walks through Portsmouth, insisting that Isambard draw buildings that interested him, and encouraging him to point out faults in its structure.

Brunel studied at the College of Caen in Normandy, then at the Lycée Henri-IV in Paris. Marc then arranged for Isambard to study under Abraham-Louis Breguet, a French clock and instrument maker who praised his technical ability. In 1822, Brunel completed his apprenticeship and returned to England.

Meanwhile, his father was busy making plans to build the Thames Tunnel, and Isambard joined him. After an accident that almost killed him, he spent six months recuperating near Bristol; here he learned of the competition for the contract to build a bridge across the Clifton Gorge.

In 1831, Brunel submitted plans for a wrought iron suspension bridge, in competition with 22 other civil engineers. When the board chose Birmingham engineers Smith and Hawkes, Brunel asked the judges to reconsider. He won the contract and received 100 guineas. Construction of the bridge began in 1831, but was severely delayed by riots and a lack of funds. Isambard would never see the Clifton Suspension Bridge finished; he died before its completion in 1864.

Brunel's engineering versatility was also evident from his exploits in the railway industry. In 1833, he was appointed Chief Engineer of the Great Western Railway, linking south west England with London. By the project's completion, Brunel had built 25 lines and had ended up exceeding his original budget by £4 million. The project involved stations, including Paddington and Temple Meads, tunnels and viaducts, all designed by Brunel.

In 1835, Brunel helped the Great Western Steamship Company design a steamship capable of crossing the Atlantic ocean, using steam continuously, rather than in a combination. Brunel had never worked on the design of a ship before, and he worked free of charge, and produced the *Great Western* – a 2,300-ton, 236-foot paddle-wheel steamship. From 1837 to 1839, she was the largest passenger ship in the world.

In 1838, the *Great Western* embarked on her first transatlantic voyage, from Bristol to New York, but caught fire before reaching Avonmouth, which almost killed Brunel. Although the damage to the *Great Western* was minimal, passengers cancelled their tickets in droves, and only seven passengers were aboard for her maiden voyage. She crossed the Atlantic in 15 days, arriving with coal to spare.

Brunel's next project was the *Great Britain*. His final project was to create an iron passenger ship to operate between London and Sydney. The *Great Eastern* was to accommodate 4,000 passengers. She was launched in January of 1858, and held the record for the world's largest passenger ship for almost 50 years. Brunel affectionately called her the 'Great Babe'. In 1859, he suffered a serious stroke dying ten days later and was interred in the family grave at Kensal Green Cemetery, London.

# John Scott Russell (1808–1882)

John Scott Russell was a Scottish civil engineer, naval architect and shipbuilder. Scott Russell was also famous for what he named the Wave of Translation, a discovery that would change ship design and shipbuilding.

John Russell was born on 9 May 1808 in Parkhead, Glasgow to David, a reverend and Agnes. His father hoped he would enter the Church, but his interest in science caused him to abandon his clerical education.

Despite having no background in engineering, Russell attended the University of Glasgow studying mathematics and engineering. It was here that he first referred to himself as John Scott Russell, incorporating his mother's maiden name into his surname. After graduating in 1825 at the age of 17, he moved to Edinburgh where he was a lecturer of mathematics. During his career as a teacher, Scott Russell taught at the South Academy in Edinburgh and the Leith Mechanics Institute. In 1832, Scott Russell temporarily filled the position of Professor of Natural Philosophy at Edinburgh. Believing one of his colleagues was also running for the position, he declined the full time job.

In 1834, while researching efficiency in canal boats Russell discovered the Wave of Translation, known in fluid dynamics as Scott Russell's Solitary Wave or Solitons. His findings resulted in him building a wave tank in the garden of his estate, where he researched the Wave of Translation for three years.

Scott Russell's theory led on to research into the shape of ship hulls; he designed numerous hulls that decreased water resistance. Scott Russell found that concave hulls were the most effective in passing through waves, whilst allowing the same wave to propel the ship.

A revolution in ship hull design soon followed, as merchants and navies alike began to realise the impact of Scott Russell's discovery.

In 1848, Scott Russell moved to London and purchased the Millwall Iron Works. It was here he started to work closely with Brunel, building the *Adelaide* and *Victoria* for the Australian Royal Mail Steamship Company. It was the construction of these ships that would lead to their most ambitious project, the *Great Eastern*.

The *Great Eastern* was far larger than any other ship of the time. Her length would only be surpassed by RMS *Oceanic* (1899) and her tonnage by RMS *Celtic* (1901). She was designed to carry 4,000 passengers and make the passage to Australia without the need to refuel. Although her design and conception can be attributed to Brunel, there was much of Scott Russell's influence, including her wave line form, her paddle engines and her bulkheads. Although the *Great Eastern* was a great engineering feat, the construction of the vessel bankrupted him. For many, Scott Russell was a talented scientist and engineer, but a poor businessman.

A keen advocate of technical education, he campaigned for a new school of Naval Architecture, after the previous had closed and published *A Systematic Technical Education for the English People* in 1869, after seeing the skills of his contemporaries from other countries.

In 1882, at age 74, Scott Russell died in Ventnor, Isle of Wight. In 1995, the Edinburgh aqueduct carrying the Union Canal where he observed his Wave of Translation was renamed the Scott Russell Aqueduct.

This approach was fostered by the new professions whose members established their own societies for the exchange of information and knowledge. Typical of this approach was the Institution of Civil Engineers (ICE), founded in 1818, whose ethos had much in common with that of the SINA. Eventually the Smeatonian Society of Civil Engineers had become more of a dining club, and a group of younger engineers demanded a better alignment to aid their profession leading to the formation of the Institution of Civil Engineers. From the outset, the Institution's members 'were guided by scientific values of justified argumentation, open debate and free disclosure of relevant information concerning new technologies and engineering events'.[9] It was patronised by the leading engineers of the day such as John Scott Russell, Isambard Kingdom Brunel, Robert Stephenson and John Rennie who, during the 1840s, could be found at the ICE's weekly meetings. A similar society, the Institution of Mechanical Engineers (IMechE), was founded in 1847; two of the first council members, Joseph Miller and Edward Humphrys, were marine engineers, and Robert Stephenson, the son of its first President, George Stephenson, also built marine engines.

Such men proved more influential than their numbers might suggest in encouraging a greater interest in a more scientific approach to ship design and shipbuilding. Brunel was the supreme engineer-cum-shipbuilder of his age. He differed from many of his older contemporaries in being extremely well educated as an engineer and scientist. He was also very well connected through his father Marc to a number of leading scientists, whose advice he often sought. He did much to try and narrow the gap between the scientific theorists and the practical engineers. Brunel more than achieved his ambition to become the leading engineer of his day, as noted by historian Andrew Lambert: 'In the space of twenty years he would perfect the wooden paddle-wheel steamship that his father had pioneered, introduce new materials into every aspect of ship structure and design, and apply a new propeller system to create the modern ship'.[10] It was Brunel's observation in 1836 that the resistance of a vessel on water increases at a lower rate than the increase in its size which has since underpinned the steady growth in ship size, leading to the largest tankers, bulk carriers and containerships of today's supremely efficient sea-going transport systems. From this, backed up by his other engineering experience, came his belief in the importance of longitudinal strength in building bigger ships. He translated his ideas into three great ships, the *Great Western*, *Great Britain* and *Great Eastern*. As another historian, J B Caldwell, noted, 'it was his successful demonstration that new things could be done, and especially that scientific and numerate argument could help to create and justify such innovations, which gave naval architecture new excitement and new confidence'. [11]

Scott Russell had also enjoyed a formal education. He studied at the universities of St Andrews and Glasgow. After graduation from the latter at the age of 17, he became an academic at Edinburgh before turning to practical engineering and then to shipbuilding. He was, recorded his biographer, 'the most scientifically educated naval architect in Britain'.[12] His research led him to establish in scientific form the best shape to move a hull through water at a given maximum speed with a minimum propulsive force, a conclusion he found to his regret was initially ignored by most shipbuilders. Despite this, the first vessel constructed under his direction using the wave system was called the *Wave* and built in 1835; it was followed in 1836 by the *Scott Russell*. In 1837, the British Association set up a Committee on Waves to conduct observations and experiments; Scott Russell, part of this Committee, made his first full exposition of his wave line theory that same year. This led to a commission for him to build a steamship along those principles, the result being the *Flambeau* launched in 1839. By then Scott Russell was Manager of Caird's yard at Greenock on the Clyde. In this capacity he succeeded in having his system employed in the construction of a new fleet of West India Mail Packets for the Royal Mail Steam Packet Company.

The *Clyde, Tay, Tweed* and *Teviot* were fitted with engines by Caird but the hulls were built by Robert Duncan of Greenock, Charles Wood of Dumbarton, and Thomson & Speirs of Greenock. Scott Russell's work on wave line theory was adopted not only by shipbuilders in Britain, who recognised the link between fuel economy and minimum resistance, but also in the USA, where it influenced the design of fast sailing clippers. He also strove to find an effective method of longitudinal framing for many years, with attempts ranging from the *Sirius* in 1834 to the *Annette* in 1862, and the *Great Eastern* in 1858.

Others shared the same approach as Brunel and Scott Russell, including Robert Napier, who met frequently in Glasgow with leading scientists like James Prescott Joule to discuss topics such as thermodynamics, and William Fairbairn, always interested in applying science to the construction of iron ships, appreciating not only the flexibility iron gave in designing new hull forms but also the complexity involved; Fairbairn wrote a practical manual which included formulae for calculating stresses and strains. At the Admiralty Sir George Cockburn, First Naval Lord between 1841 and 1846, was among those who encouraged naval architects to embrace the infant science of hydrodynamics, even though 'observation, calculation and theory had still not reached the stage at which hull shape, displacement and stability could be calculated in advance of actual construction'.[13]

The new technologies were developing gradually, and LR accordingly took an evolutionary approach towards them. Although the *Rules for Ships Navigated by Steam* was published in 1835, the Society refused to consider engines and machinery as part of the classification process. Iron ships, first appearing in the *Register Book* in 1837, were classed as 'experimental' for many years. All this was symptomatic of the Society's long view, no matter how frustrating this may have been for shipbuilders and others seeking firm guidance.

On the other hand, the Society's surveyors, employed in ports all over Britain, were an effective conduit of knowledge from one shipbuilder to another, and a number of them wrote articles for the *Mechanics' Magazine*. The Society was also aware of the need to move towards a more scientific approach to ship design and construction. In 1844, Augustin Creuze was appointed Principal Surveyor. One of the most talented students to have attended the first School of Naval Architecture in Portsmouth, Creuze, a practising naval architect, had always taken an active interest in the development of his subject and had written a lengthy article on shipbuilding for the *Encyclopaedia Britannica* in 1841. In the Introduction, he insisted that naval architecture must be treated as a science so it might 'respond to the requirements of the modern day'.[14]

## End Notes

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[3] J Fincham, *A Letter to the Right Honourable Sir James R Graham* (London, 1832) p2

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[6] R H Parsons, *A History of the Institution of Mechanical Engineers, 1847–1947* (London, 1947) p7

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[8] Sandro Mendonça, *The Evolution of New Combinations: Drivers of English Maritime Engineering Competitiveness during the Nineteenth Century*, Unpublished PhD thesis (University of Sussex, 2012) p357

[9] A Lambert, 'Introduction. The Man and his Ships', in D Griffiths et al., *Brunel's Ships* (London, 1999) pp10–11

[10] J B Caldwell, 'The Three Great Ships' in Pugsley, *The Works of Isambard Kingdom Brunel* (London, 1976) p162

[11] G Emmerson, *John Scott Russell, A Great Victorian Engineer and Naval Architect* (London, 1977) p13

[12] R Morriss, *Cockburn and the British Navy in Transition* (Exeter, 1997) p238

[13] A Creuze, *Treatise on the Theory and Practice of Naval Architecture, Being the article 'Shipbuilding' in the Encyclopaedia Britannica*, Seventh Edition (Edinburgh, 1841)

1850-1900

# 4 The metal screw steamer

By the end of this period, the metal screw steamer had become the world's standard ship as shipbuilding yards were increasing their activities on an industrial scale. Following the genius of Brunel's *Great Britain*, its potential was seen first by perceptive shipbuilders, and then taken up by shipowners as it spread across almost every route and trade. Its success depended on constant evolution, driven by an ongoing search for greater efficiency. This covered not only the ship and its constituent parts, but also the operation of the builders' yards, the works supplying engines, boilers and other ancillary machinery, and the ports and harbours handling the growing quantity of seaborne cargo. The metal screw steamer was sufficiently developed to take advantage of the opening of the Suez Canal in 1869, which not only extended its range but also delivered a serious blow to the sailing ship that until that point had developed as an effective competitor.

The Suez Canal was an important breakthrough in the development of the metal screw steamer as the workhorse of world trade. Constant improvements in its design and propulsion, coupled with larger and improved ports, drove down international transport costs, and made it possible to carry a much wider range of goods much further distances much more cheaply. By 1870, the share of world exports in world GDP had reached nearly 5 per cent and continued to rise by an average of nearly 3.5 per cent every year, outstripping the increase in world GDP. The metal screw steamer shrank the world and made a major contribution towards an expansion in international trade that seemed phenomenal to contemporaries.

The metal screw steamer became the basis, refined, enlarged and adapted, for ship development for the next 100 years. It was 'the greatest technological transformation in maritime economic history since the introduction of the Portuguese ocean-going ship in the fifteenth century'.[1] Combining the steam engine, screw propulsion and metal hull, it was a major departure from the previously accepted standard of the wooden hulled paddle-steamer or the wooden sailing ship. It was recognised as the most efficient sea-going form of transport, widely adopted by profit-conscious shipowners the world over, with Britain, the dominant maritime nation, leading the way in its development.

The prototype was Brunel's second great ship, the *Great Britain*. In this vessel Brunel brought together all the lessons he had learned in terms of materials, engines and propulsion to create the first screw-driven iron steamship purpose-built to sail the Atlantic. Following the observations he had made on board the iron-hulled steam packet *Rainbow* in 1837, Brunel adopted iron for the hull, his considerable experience as a civil engineer giving him the confidence to do so even though the vessel would be four times the size of any iron ship yet built. His design of the *Great Britain*'s superstructure, in which he emphasised longitudinal strength, was informed by his work on bridges as well as the example of the *Storm*, built by his partner John Scott Russell in 1838, which was innovative in being framed entirely longitudinally. The *Great Britain* was the greatest ship of her day, steam-powered, screw-driven, six-masted, 322 feet length overall (excluding bowsprit), she was 3,443 tons, and had a capacity of 252 passengers with cabins, but was designed to carry in excess of 300 passengers when needed, as well as 1,200 tons of cargo and up to 1,200 tons of coal. Begun in 1839, she was launched in 1843. Although she demonstrated the benefits of iron and screw for long-haul ocean voyages, she was a prototype whose high capital costs, delays in construction and teething troubles, as well as subsequent navigational incompetence, made her a financial failure. Entering service in 1845, two seasons later she ran aground in Dundrum Bay, Ireland, suffering little damage because of the strength of her iron hull. She remained there for nearly a year before being returned to Liverpool, the cost of which exhausted the company's capital, leading to her sale.

The commercial potency of the iron screw steamer was first recognised not by conservative shipowners but by more enlightened shipbuilders. In 1850 the Clydeside yard of Tod & MacGregor, which specialised in iron-hulled ships, built on a speculative basis the *City of Glasgow*. Under the yard's ownership, this vessel made four return voyages between Glasgow and New York, proving conclusively the commercial as well as technical advantages of the iron screw steamer for the transatlantic run. Competing not with Cunard's government subsidised wooden paddle steamers but with American sailing packets, she saw them off convincingly. She was snapped up by the Inman Line, one of the many new shipping companies attracted by the commercial proposition of running iron screw steamers across the Atlantic. It had taken 30 years for this to become a reality since the flop of so many similar businesses in the 1820s. The *City of Glasgow* was a paying proposition for William Inman and his partners because her iron hull required less maintenance, her screw propulsion system left more room for passengers and freight, and her moderate speed reduced her consumption of coal. Even so, it was only in 1866 that an Inman screw steamship matched the speed of the paddle steamer. This was also the era of mass migration, and within two years the ship was sailing for the US with the first steerage passengers bound for the New World.

Another of these successful unsubsidised commercial enterprises, the Glasgow & New York Steam Ship Company, also acquired several screw steamers from Tod & MacGregor. The first was the *Glasgow*, beaten home on its first voyage in 1851 by a paddle steamer by just 28 hours, a remarkable achievement given that the iron screw steamer was relatively untried and paddle steamers were in their prime. The writing was on the wall for the transatlantic paddle steamer. In 1864 the *Lafayette* and the *Imperatrice Eugenie* were the last to be built for this service, while the last paddle steamer on this route, the *Scotia*, was withdrawn in 1875.

Among the other companies that sprang up during the 1850s specifically to adopt the screw steamer was the General Screw Steam Shipping Company, which ran the first service from Southampton to New York in 1854. If many of these companies proved short-lived, this was not because of commercial weakness or defects in the ships but because of the intervention of war. When the UK entered the Crimean War in 1854, many ships on this route were pressed into service as troop transports, bringing their transatlantic services to an end.

The metal screw steamer highlighted the inter-connectedness of innovation: one often relied on another before its potential could be realised. The principal connections were between iron and steam, then iron, steam and the screw, but the marriage between component technologies necessary to achieve the modern ship remained incomplete. This situation was encapsulated in the problems evident not only in the *Great Britain*, which showed once again the need for a more efficient steam engine, but also in Brunel's last ship, the *Great Eastern*, built on an altogether much more massive scale. Launched after much difficulty in 1858, she was ahead of her time in many ways. A collaboration between Brunel and Scott Russell that ended up killing one and bankrupting the other, the vessel incorporated many advanced ideas, such as wave line form, longitudinal framing, cellular double bottom, iron decks, and complete and partial transverse bulkheads. But her ambition over-reached the limits of existing technology. In terms of size, she was five times larger than any other ship and remained unequalled until the *Oceanic* in 1899. This posed a challenge since few if any ports were capable of handling such a leviathan. This illustrated a wider problem since many ports were already struggling to cope with a steady increase in ship size. The vessel was also too big to be driven by existing marine steam engine technology. The engine driving the propellers was not powerful enough and at the time it proved impossible to design or manufacture a shaft capable of transmitting sufficient power from the engine to the propellers, as a result of which the ship was also fitted with paddles. Her engines were hugely inefficient, a contributory factor towards her size, since she had to be large enough to carry enough fuel to reach Ceylon (now Sri Lanka) via the Cape of Good Hope without taking on bunkers, a consideration that had also determined the size of the *Great Britain*. For steering, the *Great Eastern* depended initially on a manual system via wheels and chains, already inadequate for ships of a lesser size.

The deficiencies of some harbours and ports were not a new phenomenon. Even in the early nineteenth century, the size of ships had been constrained on some routes by the inability of some harbours and ports to handle them. Many ports, including London, had been congested even before the advent of the steamship, while new facilities tended to be planned to accommodate existing rather than future trade, and often failed to keep up with the pace of technological change. One such, St Katharine Docks in London, built from 1825, was already out of date when it opened in 1828, unable to cope with the new larger and deeper steamships. The situation was exacerbated because steamships had developed initially on rivers and coastal routes, outside the port system, without any regard for its limitations. When steamships began to be adopted for general cargo, many of them were already too big for established docks and harbours. Some ports well-established for centuries went into decline, eclipsed by those in major settlements, such as London, Liverpool and Glasgow, New York and Hamburg, where the volume of trade attracting the bigger ships justified the investment in new facilities. Steam dredgers built from around 1830 enabled such ports to increase the depth of channels and berths as ships got larger.

Southampton was an example of one port that responded to these changes. A steady increase in trade encouraged continuous investment in new facilities, and from the 1840s the docks became closely linked with the railways. In November 1840, P&O negotiated with the Southampton Railway Company for the carriage of cargo to and from London, and the company's engineer invited tenders for the delivery of 450 tons of coal per month.

At many ports, such as Folkestone, the railway companies were not allowed to own steamships, but exceptions could be granted by Act of Parliament. Here and in many other major ports, the partnership between the railway and the steamship created the precursor of today's global supply chains, making possible the high-volume circulation of people and goods around the world. Southampton benefited from the growth of this system, with services to the Middle East, Asia and Australasia beginning in 1845 and to South Africa in 1856. Southampton was also attractive because its deep-water approaches could accommodate ever larger ships while its location, along with its double high water tides, made it an attractive port of call for European vessels operating on transatlantic routes.

Advancing ship technology influenced the application of technology in ports. As expensive steamers became faster, time in port was ever more costly, stimulating the search for speedier turnarounds. William Armstrong was one pioneer who quickly recognised the advantages of speeding up the loading and unloading of ships. His brilliant idea was the application of hydraulic power, and in 1846 he began converting existing quayside cranes in Newcastle to hydraulic operation. A visionary as well as an entrepreneur, Armstrong understood the importance of his invention for shipping and industry, placing it within the context of the march of industrial progress. He backed his invention with his own money, supported by his friends, and began making purpose-built hydraulic cranes, which became the foundation for his business empire. In 1887, Armstrong became the first engineer and the first scientist to be elevated to the peerage as the first Baron Armstrong.

Hydraulic cranes were essential to cope with bigger ships. Larger and larger ships posed challenges for every dock and harbour engineer, which many struggled to overcome, continuing to adopt a piecemeal approach that failed to keep pace with change.

A fortuitous exception was Liverpool's Canada Dock, opened in 1858, its entrance lock built 100 feet wide, an exceptional width for the time, to accommodate the paddle-boxes of ocean-going paddle steamers; this proved ample for the next generation of steamers. Conversely, the dock basins adopted in many other ports, including London, were inflexible in accommodating bigger ships.

Nearly half a century after the fuel inefficiency of the marine steam engine had first been acknowledged, the need for a more powerful yet more economical engine was even more pressing for the realisation of the full potential of the steamship. Longer routes were still dominated by the fast sailing ship, as the steamship was still disadvantaged both by the need to carry lots of coal at the expense of cargo space and by the need to stop more frequently at coaling stations on long voyages. It was reckoned in 1855 that coal and machinery together could account for as much as 44 per cent of a ship's total capacity. These coaling stations, originally supplying the needs of the first steam mail and passenger services, helped to overcome part of the problem. Companies such as the Bibby Line had set up their own coaling stations at Genoa, Messina, Lisbon and Oporto by the mid-1850s. But while Bibby steamers plied the Mediterranean, coaling stations on other routes took longer to establish, and Bibby still used sailing ships for voyages to India and South America. Coaling stations were generally situated along major shipping routes, owned and fuelled by the British. Providing an important export market for British coal, they were supplied by sailing ships, since speed was not of the essence. By the 1870s, P&O chartered a fleet of 170 sailing colliers to maintain its steamship service to India. By 1914 there were 181 coaling stations along the world's main trading routes.

# William Armstrong, Baron Armstrong (1810–1900)

William Armstrong was an influential industrialist who formed the Armstrong Whitworth manufacturing company, one of the largest works in Newcastle in the early twentieth century. He was also a successful scientist, inventor and philanthropist.

Armstrong was born in Newcastle upon Tyne on 26 November 1810 to William and Ann. Until he was 16, William was educated at private schools then studied law at Bishop Auckland and London. In 1835, he became a junior partner in the law firm of Donkin, Stable & Armstrong and married Margaret Ramshaw, the daughter of a local builder and engineer.

It was at this time that Armstrong decided to pursue his love for engineering; his first engineering commission was for Newcastle Corporation, a scheme to provide piped water to Newcastle homes. It proved so successful that there was enough excess pressure to power one of the quayside cranes, the time saved loading and unloading vessels persuaded the Newcastle Corporation to commission three more.

In 1846, Armstrong gave up law to learn mechanical engineering and Donkin agreed to fund his next engineering project. Armstrong set up his own firm, W G Armstrong & Company, and developed 5.5 acres of land close to the River Tyne at Elswick. The company immediately received orders for hydraulic cranes and gates from the ports of Grimsby, Liverpool and Edinburgh.

In 1855, Armstrong decided to diversify, offering bridge building and armaments. He designed and built a light, easily manoeuvrable gun for use in the Crimean War. Armstrong donated his patent to the British Army, a gesture that earned him a knighthood and the job of Engineer of Rifled Ordinance at the War Department.

In 1864, Armstrong decided to merge W G Armstrong and the Elswick Ordinance Company. The new company, Sir W.G Armstrong & Company, produced naval guns, with a separate company run by Charles Mitchell who built the ships. The partnership's first ship was the gunboat HMS *Staunch* in 1868. One of Armstrong's biggest issues in constructing warships was an eighteenth-century bridge, which prohibited access to the Elswick works. In 1876, Armstrong paid for a swing bridge to be built, so that guns could be fitted to ships at the Elswick works.

In 1882, Charles Mitchell and Armstrong formed an official partnership, Sir William Armstrong, Mitchell and Co. Ltd. Two years later, a new shipyard was opened specialising in warships; this would later manufacture the *Panther* and the *Leopard* for the Austro-Hungarian Navy. Armstrong also helped build the HMS *Victoria* in 1887, the same year he was made Baron Armstrong of Cragside, making him one of the first engineers to sit in the House of Lords. In 1894, the Elswick factory constructed and installed the steam-driven pumping engines, hydraulic pumping engines and hydraulic accumulators for Tower Bridge, London.

Armstrong once again expanded his business in 1897 when he merged with his long-time rival Joseph Whitworth to form Sir W G Armstrong, Whitworth & Co. Ltd, which employed the best, most innovative engineers of the time. Three years after the merger, Armstrong died, aged 90, and was buried at Rothbury. Even after death, Armstrong displayed his generosity, leaving £100,000 to build the Royal Victoria Infirmary in Newcastle.

The London-based coal merchants Wilson, Sons & Co. Ltd owned coaling stations in St Vincent, Pernambuco, Bahia, Rio de Janeiro, Santos and Montevideo, each supplied with the best South Wales coal, with tug boats on hand at every depot. Coaling stations also developed as repair depots, and were available to all forms of steam shipping, notably long-distance cargo steamers equipped with compound engines. While they were convenient for steamships, and helped them to complete longer voyages, they did nothing to make them more economic, since coal shipped long distances from the UK was more expensive.

Compounding, that is, achieving higher pressures through the use of multiple cylinders, utilised steam more than once before returning it to the boiler, resulting in a significant reduction in fuel consumption. The idea was first patented in 1781 by Jonathan Hornblower and again in 1805 by Arthur Woolf. Thereafter, however, it was largely ignored, thanks to the primacy of paddle propulsion and the gradual pace at which boiler technology developed, since early boilers could not sufficiently or safely stand the higher pressures needed to operate the compound principle.

## The Bessemer process

The Bessemer process was applied in mass steel production which involves the removal of impurities such as carbon and silicon from pig iron through oxidation. Hot, pressurised air is blasted into a tilting Bessemer Converter.

The process was developed by the engineer Henry Bessemer (1813–1898) to manufacture cheap steel in bulk through an open furnace. The process revolutionised the British steel industry, then that of the United States and Sweden. Its efficiency meant that the price of steel was slashed, steel workers' working conditions became much safer, and imported pig iron was reduced. Bessemer's method meant that steel was used in greater quantities, including in bridge building, rail works and shipbuilding. In the latter industry it could be used in safer boilers and shipping cables, while increasing the efficiency of gears and engines.

The Bessemer process was superseded by basic oxygen steelmaking, which reduced smelting time, increased labour productivity and reduced costs. It was still widely used in continental Europe, as many European iron ore resources had a high phosphorus content, which could not be removed by the basic method; Germany used the Bessemer process for nearly all its steel until the 1950s. Many historians and engineers credit the process for mass industrialisation during the twentieth century.

## The Siemens-Martin process

The Siemens process (or Siemens–Martin process) was created by Carl Wilhelm Siemens and the French engineer Pierre-Émile Martin.

Similarities between Bessemer's method and the Siemens process included the oxidisation of iron when exhaust gases were released back into the furnace. While the Bessemer process used air to oxidise the iron ore, Siemens used oxygen, creating more stable steel. The Bessemer process had a much faster rate of melting whereas the Siemens process was much slower, on average taking a number of hours for the iron to be melted and refined.

The processes also differed in the specifications of their furnaces. Bessemer required tilting furnaces so that the steel could be exposed to manganese and carbon, increasing its robustness and stability. In contrast, the Siemens process relied on a reversal of oxygen flow.

Both Bessemer's process and Siemen's method were considered outdated in 1900, when basic oxygen steelmaking became the process of choice for steel manufacturing in Britain. This did not mean that the open furnace methods were redundant, as Eastern European countries continued to use furnaces in steelmaking; in countries such as Ukraine and Romania, open furnace methods were used into the late twentieth century.

It only became the subject of serious attention after screw propulsion began to be adopted during the 1840s and 1850s, by which time a growing understanding of thermodynamics had shown that engines with higher pressures were much more efficient. In 1853 Charles Randolph and John Elder patented the first successful marine compound engine. Installed on board the *Brandon* in 1854, it was claimed to improve fuel consumption by as much as 40 per cent. Although the savings were attractive, the initial troubles of some early compound engines once again deterred shipowners from taking up the new technology.

P&O installed a compound engine in its new steamer *Mooltan* in 1861 as a way of overcoming coaling problems on the long route to Asia, but few followed suit until the late 1860s and early 1870s. Once again this highlighted the time lag between invention, innovation and wider adoption, in this instance stretching over nearly a century. Compounding had become viable only as other associated technology became more sophisticated and there was a better understanding of the science involved. It was more widely taken up only once the economic advantages outweighed the cost of initial technical problems.

Although compound engines improved, helped by the expiration of Randolph and Elder's patent in the 1870s, compounding alone was insufficient to raise the efficiency of the steam engine. Once again the full potential of one innovation could not be realised until another innovation had taken place. The weak link, as P&O discovered, was the marine steam boiler, which was not up to the job of generating a constant supply of sufficient steam. Again this was not a new problem. Over half a century the pressure generated from the existing type of boiler had risen from as little as three pounds per square inch (psi) before 1830 to no more than 15 psi by 1850. Early attempts to develop higher-pressure boilers had failed, since the iron used was too impure to create the thicker plates needed to withstand increased pressures. There had been a number of explosions, with associated casualties, and the Board of Trade and LR regarded them as too dangerous to use at sea. These early boilers also tended to salt up, resolved through the invention of the surface condenser in 1838, although this was ignored for years by many engineers. It was only in 1862 that a more reliable high-pressure boiler, the Scotch boiler devised by the Glasgow consulting engineer James Howden, at last appeared. Made possible in part because of improvements in the way iron was made, this was a fire-tube boiler, developed originally for railway locomotives, and adapted by Howden for marine use. An alternative to the Scotch boiler, the water-tube boiler, first patented by the French firm Générateurs Belleville, had appeared in the 1850s, but it proved much less reliable, and the Scotch boiler remained the boiler of choice for smaller merchant steamships. An improved water-tube boiler was adopted by naval vessels in the 1890s to cope with the varying power demands of a warship, but it was not until the 1920s that it was widely used for larger merchant ships.

Once more innovation was driven by commercial considerations. In 1864, attracted by the potential of the profitable China trade, Alfred Holt combined his own version of the compound engine with a high-pressure boiler in his experimental steamship *Cleator*, producing fuel savings of 40 per cent. As a result, Holt commissioned three new steamships featuring the same combination, which could not only sail the 8,500 miles from Liverpool to Mauritius without coaling but also carry up to 3,500 tons of cargo. Holt's commercial success was assured and he set an example for others to follow. By the 1870s the combination of the compound engine and Scotch boiler had more than proved itself. It began to be adopted by the conservative owners of the expensive and prestigious vessels that criss-crossed the North Atlantic, such as Cunard's *Servia*, launched in 1881. The first large ocean liner to be built of steel instead of iron, *Servia* was also the first Cunard ship fitted with an electric lighting installation. Operators discovered that the saving made through increased economy from better engines and boilers allowed them to secure a more competitive position by offering lower freight rates.

## Alexander Carnegie Kirk (1830–1892)

Alexander Carnegie Kirk was an innovative mechanical engineer and inventor. In 1871 he joined Randolph, Elder & Co. as their engine works manager, where in 1874 he retro-fitted their triple-expansion machinery installation to the *Propontis*, a ship that had been built ten years earlier. But the engine was not successful due to lack of boiler pressure, and Kirk moved to Robert Napier & Sons. With the advent of steel Kirk was able to revisit his ideas resulting in George Thomson & Co. agreeing to a triple-expansion engine being fitted to their steamer *Aberdeen*, being built in 1881 by Napiers. The boilers supplied steam at 125 psi and the remarkable 30 per cent fuel economy achieved saw other owners reconsidering their ideas and in some cases replacing their machinery.

In the 1870s, many ships with simple expansion engines were converted to compound engines. From the late 1870s, stronger boilers capable of higher pressures of around 70 psi for compound and 150 psi for triple-expansion engines began to appear, as iron was replaced by the better quality steel made through the Siemens-Martin process, superseding the earlier Bessemer process.

This in turn led to the double-expansion compound engine being superseded by the triple-expansion engine, where steam was expanded successively in at least three separate cylinders. This was largely the invention of Alexander Kirk, a brilliant university-educated engineer with a doctorate, whose first attempt at the triple-expansion engine in 1874 while he was working for John Elder & Co. came to grief because of boiler problems. Having moved to Robert Napier & Sons, Kirk persisted with his idea. The firm was asked to build a vessel for the Aberdeen Line's new service to Australia. Bunkering considerations for this long-haul route had long hindered the introduction of the steamship; for example, it was calculated in 1851 that a 1,400-ton vessel making the 41-day voyage across the Pacific at 8.5 knots would have to carry 800 tons of coal. Kirk was convinced that the new steamer would be much more economic if equipped with the combination of a triple-expansion engine and strengthened Scotch boilers to allow higher pressures. The *Aberdeen*, launched in 1881, proved hugely successful, consuming just 40 tons of coal a day while sailing at 12 knots. The new engine proved to be one-third more efficient than the compound engine, working at 125 psi compared with the 70 psi of its predecessor. The fuel economy of the triple-expansion engine made it commercially attractive. When Holt's ship *Glenfruin*, built in 1880 with compound engines, consuming 95 tons of coal a day, was converted to triple-expansion engines in 1891, consumption dropped to 56 tons a day. By the early 1880s average steam pressures had reached 130 psi, rising to as much as 180 psi by the late 1880s, while the consumption of coal had fallen to as low as one and a quarter lbs per ihp per hour compared with three to ten lbs in the 1850s.

Further savings came through another of James Howden's inventions, the forced draught system, which also allowed the use of cheaper slack coal rather than lump coal. It was now possible for ships to steam from Liverpool to New Zealand without calling to replenish coal. The other big advantage of the triple-expansion engine, which contributed towards its long service, was that it developed almost as much thrust astern or in reverse, and it could operate at slow speeds, giving ships great manoeuvrability.

Many copied Kirk's idea, developing more powerful triple-expansion engines, facilitating the design and construction of larger and faster ships. Once again owners proved conservative in their approach, but were persuaded to adopt the new technology on the advice of shipbuilders; they soon appreciated the cost savings and increased profits that came from running more efficient engines. John Scott Russell emphasised the virtues of the new engines to his peers in 1877: 'Look at the advantages for steam navigation: your engines in much smaller space; your coal in much smaller space; not only the cost of the coal less, but all the room left for the carrying of profitable cargo. Is that worth your while or is it not worth your while?'[2]

Compact, efficient, reliable, simple to operate, and needing little maintenance, the triple-expansion engine became the workhorse of the world fleet for decades. In 1889 Alfred Holt even stated that fuel economy was no longer a priority since coal had become such a small proportion of shipping costs, for example it cost well under £1 per ton in the UK. This was the year when the Inman Line's *City of Paris* was launched, joining her sister, the *City of New York*. They were the most advanced ships of their day, with twin triple-expansion engines, each with an engineering crew 174 strong including greasers and stokers. Their example stimulated competition from rival operators, accelerating the pace of marine machinery development, and stretching existing technical developments to the maximum.

There were many other lesser improvements waiting to be made to achieve the complete modern vessel. The solution to the problem of steering ever larger ships came from John Macfarlane Gray, a manager with the Liverpool engine builder George Forrester & Co., whose steam steering gear was designed to exercise sufficient control with minimum effort. This innovation, retrofitted on the *Great Eastern* in 1866, was described in a paper presented to the Institution of Mechanical Engineers (IMechE) in 1867, and by the 1870s it was being fitted to all large steamers. In the 1860s petroleum-based lubricants became available, replacing the animal- and vegetable-based lubricants which had proved unstable at higher pressures and temperatures. New materials, such as asbestos, were adopted for joint sealing and piston packing to withstand higher pressures, and sealing rings were pioneered in 1852. More efficient surface-condensers were designed to prevent the leaking of lubricants into engines, while the water-lubricated lignum vitae tube bearing, devised as a direct result of the problems afflicting the *Great Eastern* on her maiden voyage, increased the efficient propulsion of power to the propeller. Larger cargo hatches speeded up cargo handling. Historian David K. Brown observed: 'Not for the first time – or the last – a major advance in engineering depended on apparently minor details.' [3]

It should not be forgotten that this steady technological advance depended in itself on a myriad other improvements elsewhere. Without the steam hammer, invented in 1839, the economic production of crankshafts and other heavy forgings would not have been possible. The screw-cutting lathe and planing machine made possible accurate and reliable machinery. Then there were standardised screw threads, surface plates, plug and ring gauges and measuring machines. The 1850s saw the development of specialist marine engine builders in place of the general land-based engineering firms. In other words, science had become indispensable for marine engineering.

Shipbuilding was beginning to take place on an industrial scale as capital became available in financial markets. From a standing start in the early part of the century, the shipbuilders who had begun as engineers and iron founders had created complex organisations, employing a large and varied workforce, with a wide range of skills, from platers and riveters to caulkers and drillers. In the UK, which dominated world shipbuilding as well as shipping, the industry was mainly sited close to the major iron and engineering works in growing industrialised areas such as Clydeside, Tyneside and Wearside. Some shipyards, especially tramp shipbuilders, concentrated on hull construction, relying on subcontractors for the supply of engines and machinery, but most of the larger liner builders had taken up engine building by the 1880s. Shipyard workers too relied on improving machinery to tackle ever bigger vessels, such as hydraulic punches and shears, pneumatic riveting machines, hydraulic gantries, derricks with winches and, later, electric cranes. By 1905 the hull of the liner *Carmania* used 1.8 million rivets, some seven inches long and weighing three and a half pounds each. 'The art of shipbuilding had passed into the hands of metal workers, and the construction of ships had become an intricate business, a combination of many industrial processes, not all of which were carried on in the shipyard.'[4] In essence shipbuilding became an assembly industry, which it remains to an even greater extent today.

As the steamship progressed and became more reliable and economical, the sailing ship struggled to remain competitive on certain long-haul routes as well as coastal bulk trades and other intermediate routes. Nonetheless, on longer routes, sailing ships still competed with each other rather than with steamships. Profit lay in speed rather than volume, and the sailing ship could swiftly carry specialised cargo, such as tea, from port to port. Where winds were predictable, profit lay in volume rather than speed, such as in the Australian wool and grain trades, and the jute and sugar trades; here again the sailing ship prevailed for a little while longer. The design of these long-distance sailing ships was often influenced by external events, like the Gold Rushes in Australia and California, which demanded larger, faster ships. The US had long held a reputation for building fast sailing ships, long and narrow, with sharp bows and sterns, and they competed successfully with paddle steamers on transatlantic routes until the onset of the American Civil War in 1861.

With the advantage of plenty of cheap timber, US shipbuilders were constructing sailing ships of up to 2,000 tons, and on the routes to US west coast ports the sailing ship remained dominant, specifically in trades like lumber, until 1914. The streamlined UK clipper was epitomised by the *Thermopylæ*, a composite ship designed by Bernard Waymouth, Principal Surveyor and later Secretary of LR, which was six times longer than she was broad. During the 1860s she set a record of 60 days for the voyage between London and Melbourne, while similar vessels shaved nearly three weeks off the sailing time from England to China. Although these greyhounds of the oceans were in a minority among sailing vessels, their speed and efficiency spurred on demand for cheaper, more efficient ocean transport, which ultimately led to their role being overtaken by the increasingly efficient steamship.

As the example of P&O's sailing ships transporting coal to coaling stations shows, the sailing ship as a carrier of bulk cargoes, for which speed was unimportant, could still hold its own along intermediate routes against steamships whose cargo space was limited and precious. The coasting trade too was still dominated by the sailing ship. By the early 1870s one of the largest sailing fleets in the UK belonged to James Fisher of Barrow, wholly engaged in the coasting trade. His fleet was made up almost entirely of small schooners, cheap to operate, easy to handle, and speedy. Fisher had experimented with steam in the late 1850s but had experienced so many problems that he converted his steamships to sail in the early 1860s. It was only in 1883, once the major improvements had taken place, that the company invested in steam once more. In fact, rather than the steamship, the sailing ships in the coasting trade experienced greater competition from the railways, which could run to fixed schedules not constrained by the vagaries of wind and tide.

To remain competitive, the sailing ship also made use of the new technologies. They had been the first to benefit from the advantage of the iron hull in creating more internal cargo space. Iron masts and wire rigging were stronger and more durable than wood and fibre ropes. They also adopted labour-saving devices, such as steam winches and capstans. As a result, by the 1870s the most efficient sailing ships had twice the capacity of older wooden ships and carried one-third fewer crew members. They also retained the advantage of being cheaper to build and crew than steamships.

After 1850 more and more sailing ships were built of iron as metalworking processes improved and the price of iron fell. The year 1854 saw not only the wooden sailing ship reach its zenith, with the building of the 346-foot *Adriatic* for the Collins Line, which historian David Pollock noted was 'altogether beyond the then recognised standard rules for shipbuilding'[5] but also a vivid demonstration of the superior strength and resilience of the iron hull, when the iron-hulled steamship *Vesta* collided with the wooden paddle steamer *Arctic*. The latter sank, with the loss of 315 lives, but the *Vesta* made port without a single fatality.

Iron sailing ships became larger during the 1860s and 1870s thanks to the ability to make much larger iron plates. The myth that iron hulls tainted the flavour of foodstuffs was demolished with the voyage of the coffee-bean-carrying steamer *Halley* from Rio de Janeiro to New York in 1865. As for wooden-hulled vessels, by the 1880s Canadian shipyards had abandoned the sale of wooden tonnage overseas, although protectionism helped US builders to continue making large wooden sailing ships into the 1890s. The wooden shipbuilding skills of the US and Canada were to be temporarily revisited during the First World War to help with the demand for more tonnage.

From the 1850s onwards, sailing ships of composite construction were made in the UK and France, popularised in particular by the Scottish shipbuilder Alexander Stephen. The advocates of composite construction based their claims on the general theory that iron was better than timber only for certain aspects of construction. Stephen not only corresponded directly with other builders as well as owners, but also persuaded LR to classify composite vessels, leading to the *Rules for Composite Ships* in 1868. As a result, this method became 'a well-supported movement by numerous shipbuilders and backed by firm orders secured after much deliberation and discussion with shipowners, who required convincing arguments about the new system'.[6] While composite vessels of up to 2,000 tons were able to compete with US clippers, overall output of composite sailing ships was small. By the 1870s it was clear that iron was superior in almost every aspect other than fouling, for which coatings were already being developed. The last UK composite sailing ship was launched in 1876 although composite ships were still being built in the Netherlands in the 1880s.

By then the steamship had breached the sailing ship's last bastion, the long-distance routes to Asia, Australia and New Zealand. The catalyst was the opening of the Suez Canal on 17 November 1869, when the paddle steamer *Delta* became the first ship to pass through from north to south. The Canal transformed the prospects for the steamship on long-distance routes. Prior to its opening, the realisation of the dream of a visionary entrepreneurial opportunist, Ferdinand de Lesseps, there had been two options for travelling to India: taking a steamer to Alexandria, then travelling overland to Suez to pick up steamers for the onward journey; or taking a sailing ship on the much longer route around the Cape of Good Hope. Although there were initial problems for steamships navigating the Canal, for sailing ships the Canal was not a realistic alternative – lack of wind meant they would have had to be towed through the Canal and then face the hazards of navigating the Red Sea. The excessive cost of towing ships through the 100-mile-long Canal meant that between December 1869 and April 1875 only 238 sailing ships traversed the Canal out of 5,236 ships.

The impact of the Canal was immediate. By 1870, one observer could write that 'the production of sailing ships since the opening of the Canal has been almost, if not entirely, stopped' and predicted that the likely outcome would be 'a general substitution of steam for sails in the great carrying traffic from the East'.[7] He also made two shrewd observations about the impact of ship technology in relation to the Canal. Had the Canal opened a decade earlier, it would have been of little advantage for the less sophisticated, smaller steamships with their poor fuel consumption. And while steamships would now take over the Indian traffic, the fast clipper would still have a place on the longer route to China, until there were further improvements in the steamship's cargo capacity and fuel consumption.

British shipowners soon began to tailor the size of their steamships to the dimensions of the Canal, which in time would be enlarged to take bigger ships. New shipping companies, such as Nederlandsch-Amerikaansche Stoomvaart Maatschappij (NASM) (the Holland-Amerika Lijne) and the Stoomvaart Maatschappij Nederland (SMN), were formed to take advantage of the shorter routes. It was only in the early 1880s, suggested one writer in 1924, that 'the Canal settled down to be the regular route we are familiar with today'.[8]

# Alfred Yarrow (1841–1932)

Alfred Yarrow was a marine engineer and shipbuilder, the founder of Yarrow Shipbuilders, which operated for 112 years.

Yarrow was born in January 1842 to Edgar Yarrow, a London merchant and Esther the daughter of a West Indies merchant. He was educated at University College School, London where it was noted he had a talent for mechanics. At the age of 15, he was apprenticed to Ravenhill, Salkeld & Co. a marine engine builder in East London.

In 1865, Yarrow formed a partnership with a Mr Hedley, establishing a general engineering factory on the Isle of Dogs, London. After his and Hedley's partnership ended in 1875, Yarrow kept the Isle of Dogs works. A few months later, he married Minnie Franklin, the couple would go on to have three daughters and three sons. Harold Edgar Yarrow, the eldest son, inherited his father's business.

Soon after taking over the London yard, Yarrow expanded his business, working on shallow-draught river and lake boats, orders for torpedo boats came in, boosting Yarrow's business while also allowing him to diversify his work, from small river vessels to warships such as destroyers. During this time, he developed and patented the Yarrow boiler, a water-tube boiler, which was first used on a torpedo boat in 1887 and installed on many of the warships his yard built, as well as many merchant ships. In 1898, Yarrow moved his yard to Cubitt Town and continued to manufacture warships, including those for the Royal Navy, the Japanese Navy, and the Swedish and Russian Navies. Despite moving yards, the company outgrew the London site and in 1906 moved to Scotstoun, on the River Clyde. The move was driven by high wage rates and industrial disputes in London.

In 1913 Yarrow constructed works in Esquimalt, Canada, and that same year, now aged 71, retired to his home in Hampshire. However, the outbreak of the First World War brought him out of retirement; his company built 29 destroyers and pioneered a design for shallow-draught gunboats used in Mesopotamia. His war work gained him a knighthood in 1916, a year after his youngest son Eric had died, aged 20, in the conflict.

Yarrow was a great philanthropist and understood the great value of research; he donated £20,000 for the construction of a test tank at the National Physical Laboratory at Teddington and gave £100,000 to the Royal Society to fund a number of scholarships and research professorships. He bequeathed money to various institutions including the Royal Institution of Naval Architects and the Institution of Civil Engineers. Yarrow died, at the age of 90, on 24th January 1932. Yarrow's great grandson, Alderman Alan Yarrow, was elected Lord Mayor of London in 2014.

On the Bombay route steamships could charge higher rates and still undercut sailing ships coming round the Cape, while on other long-distance routes they were able to compete at prevailing rates. The steamship's encroachment around the globe was impressive: in 1850 the sailing ship held the advantage on routes longer than 3,000 miles, but by 1890, only beyond 10,000 miles did it still hold some advantage, and even on these routes most high-value cargo, and passengers, travelled by steamship.

The ascendancy of the steamship was assured by the substitution of steel for iron. The primacy of iron was short-lived. When shipowner John Good visited Newcastle in 1864, he had recorded after a trip down the Tyne that 'I was struck in looking over the different shipbuilding places to notice that nearly all were using iron only, scarce a wooden ship to be seen, I think we only noticed two or three'.[9] Yet even as John Good made his voyage, the first steel-hulled ships were already at sea, notably including blockade runners in the American Civil War, where shallow draft and high speed were essential to avoid the blockading Federal warships. While the 'constructional revolution wrought by iron construction was of a width and depth far surpassing any other in constructional methods which has ever taken place in the history of shipbuilding',[10] the use of iron had peaked by the late 1880s as better quality steel became more widely available at cheaper prices.[11] The first steel vessel was John Laird's *Ma Roberts* in 1858, shipped out to Africa for reassembly and use by David Livingstone on the Zambezi. In 1860–1861 several steel-hulled cross-Channel packets were built, and in 1865 LR classed the part-steel steam yacht *Mahroussa*, built for the Khedive of Egypt. This was followed in 1866 by the first steel ship approved by LR, the *Annie* built by Samuelson of Hull in 1864. LR accepted better quality Siemens-Martin open hearth steel in 1877, when one Newcastle shipowner, commissioning a steel vessel for the Bilbao iron trade, calculated that the advantages accruing from a reduction in weight, including an all-steel Scotch boiler, more than outweighed the cost.

With their experience of iron construction, shipbuilders adapted easily to the new material, which required few structural changes in ship design. The Siemens-Martin process also turned out heavier ingots, which allowed larger plates to be rolled, thus reducing the number and length of riveted joints. Perfected for shipbuilding, mild steel had greater advantages over iron than iron had had over timber. It was stronger, it was more likely to distort than fracture in a collision or grounding; its elasticity mitigated the more violent impact of the sea; and it was 15 per cent lighter, reducing the weight of the hull from 50 per cent to 30 per cent of displacement, providing the scope for carrying heavier cargoes and helping to reduce fuel consumption further. Historian Leslie Jones noted that at first the cost of steel did not outweigh the economic advantages of increased carrying power and freight earning capacity, but steadily this disparity vanished and by 1900 steel was cheaper and widely available. Even by 1880 the advantages of steel had become so obvious that there was a great deal of criticism of the recently launched *City of Rome*, almost as long as the *Great Eastern* and the pinnacle of merchant shipbuilding at the time, for being made of iron. In little more than 20 years since the first steel-hulled vessels had been built, a relatively short time span by comparison with many other innovations in ship technology, steel was in general use. In 1879 the 4,000 gross registered tons (grt) *Buenos Ayrean* of the Allan Line was the first steel vessel on the South Atlantic run, while the first large Atlantic liner made of steel was the 7,392 grt *Servia* built in 1881. Another breakthrough came in 1894 when the shipbuilder Yarrow & Co. Ltd used high-tensile steel for the first time in part of the construction of a Russian torpedo boat destroyer, the *Sokol*. Stronger but thinner, high-tensile steel made vessels even lighter and faster, and Yarrow's warship was the first vessel to reach 30 knots. By 1900 steel had almost entirely replaced iron for shipbuilding.

# Sir Charles Algernon Parsons (1854–1931)

Sir Charles Algernon Parsons (1854–1931) was an English engineer and scientist known for his invention of the steam turbine in 1884.

Parsons was born in Connaught Place, London, on 13 June 1854 to William and Mary Parsons. William encouraged his children to study science and engineering.

At 17, Parsons went to Trinity College, Dublin, where he studied for two years before moving to St John's College, Cambridge, to study mathematics, graduating in 1877. Although St John's did not have an engineering course, Parsons attended lectures on applied mechanics.

Parsons joined Sir William Armstrong & Co. at Elswick, Tyneside, as an engineers' apprentice. After four years he moved to Kitson & Co. in Leeds, where he helped to build rocket-powered torpedoes, and constructed and patented a four-cylinder, high-speed steam engine.

In 1884, Parsons became a junior partner in Clarke, Chapman & Co., a marine and electrical engineering company in Gateshead. Parsons realised he could invent a turbine to convert the power of steam into electricity, and Parsons' steam turbine was built. Within four years, over 200 were constructed; the majority were used on board ships for lighting.

Parsons formed C A Parsons & Co. based in Heaton, Newcastle upon Tyne. Parson's company manufactured a number of turbo-alternators for use in power stations in Scarborough, Newcastle and Cambridge. The growth of electricity supply meant larger generating units and higher transmission voltages.

In 1894, Parsons developed his marine steam turbines. He formed a new company, Parsons Maritime Steam Turbine Company, at Wallsend. *Turbinia* was fitted with a steam turbine and attained a speed of 34 knots, and was the fastest vessel afloat at the time.

Following earlier Admiralty commissions, Parsons designed the *Velox* and the *Amethyst*, persuading the Admiralty to specify all warships built after 1905, be powered by turbine. Cunard were the first to install these turbines into the merchant fleet, *Carmania*, being the first ship of her kind. She was followed by *Lusitania*, and *Mauretania*, which held the Blue Riband for almost a quarter of a century.

Parsons focused on mechanical reduction gearing, to improve the efficiency of the turbine and the propeller. In 1909, he replaced the 750 hp triple-expansion engines of the *Vespasian* with his mechanical gearing. Another engineering success, it diminished engine size allowing more space for turbines and cargo.

On 11 February 1931, Parsons died aged 77, on board the *Duchess of Richmond* in the Caribbean. During his career, he had taken out more than 300 patents. He was awarded a number of accolades, and was knighted in 1911.

Another technology adapted just as rapidly as steel was the steam turbine. Invented in 1885 by Charles Parsons, a graduate in maths and science, the steam turbine, like the steam engine, was initially used on land, in this instance for the generation of electricity. But Parsons was quick to see the advantages for shipping and completed a fuel-efficient marine version in 1892. The speed record of Yarrow's torpedo boat was soon broken when Parsons' small 45-ton experimental *Turbinia*, also launched in 1894, achieved a speed of 34.5 knots after modifications in 1897. One of the problems raised during the trials of the *Turbinia* was what later became known as cavitation, in that the rapid rate at which the screw was driven by the turbine led to a substantial loss of thrust. Observations were made of the phenomenon by Sir John Thornycroft and Sidney Barnaby during the trials of HMS *Daring* and revealed publicly in March 1895. Parsons developed the world's first cavitation tunnel to observe the cavitation taking place in model scale and make quantative measurements of its effects. He subsequently installed three parallel flow turbines and three propellers on each of the three screw shafts of *Turbinia* in 1896, and by 1897 she was making speeds of 34.5 knots.

The steam turbine had many advantages – speed, fuel economy, less vibration, reduced weight and cheaper initial costs at higher powers. It was also more compact, releasing more space for carrying cargoes or passengers. Parsons was a reluctant speaker to the INA in 1897, since the trials of the *Turbinia* were still incomplete. Few in attendance appreciated the significance of his invention, with most speakers stressing the experimental nature of the turbine and the disadvantages of a high rate of revolution. But two shipbuilders, John Thornycroft and Alfred Yarrow, both appreciated the turbine's potential, with Yarrow describing Parsons' paper as one of the most valuable and historical ever likely to be presented to the INA.

By 1901, after further work to minimise the impact of cavitation, the *King Edward*, a small prototype passenger steamer fitted with three turbines, showed a fuel saving of 15 per cent over a similar vessel powered by triple-expansion engines. She became the first commercial vessel to be driven by steam turbines and was remarkably successful, serving as a Clyde steamer for half a century. Her success also led to the adoption of turbine propulsion for all manner of merchant vessels and, remarkably, within three years the steam turbine was being fitted to what would become the world's largest and fastest merchant ships, the prestigious Cunard transatlantic liners *Lusitania* and *Mauretania*, achieving speeds of 24 to 25 knots. LR played a key role in this project. James Milton, the Chief Engineer Surveyor, was a member of the Cunard Committee which decided to opt for turbines, the ships were built under the Society's special survey, and Society staff acted as superintendents throughout construction.

By 1900 the metal screw steamer was conquering the globe. Sailing tonnage in the British fleet, the largest mercantile marine in the world, fell from 3.3 million tons in 1886 to 750,000 tons in 1910. This decline was mirrored in other merchant fleets, whether in the US, where sail fell from 1.6 million tons to 1.1 million tons, or Norway, where it halved from 1.3 million tons to 600,000 tons. The steamship could finally dispense with sails.

Steam triumphed in the Mediterranean after 1870, while the major shift to steam on transatlantic routes took place during the 1880s and on routes to South America during the 1890s. The opening of the Suez Canal made a dramatic difference to the take-up of steam on routes to India and Asia, while the last routes to succumb to steam were those to Australia and the US west coast. By 1883 the steamer had overtaken the sailing ship in terms of aggregate tonnage and by 1904 in terms of overall numbers. In the coasting trade sail gave way to steam by 1914 as the transition drastically reduced shipping costs.

The superiority of the metal screw steamer was based directly and indirectly on technology; not just better engines and boilers, lighter weight, greater reliability, easier navigation and size, but also the support given by improving cargo-handling facilities and port infrastructure and by better shipbuilding methods. Voyages were certainly faster, since the steamship provided a regularity of service the sailing ship could not, but other than on the prestigious transatlantic passenger routes it was size rather than speed that drove the efficiency of the steamer as owners sought economies of scale. Between 1870 and 1880 the size of the average cargo steamer nearly tripled, from 1,050 grt to 3,000 grt.

By the early 1900s the biggest steamships, such as the White Star Line's big four, *Celtic*, *Cedric*, *Baltic* and *Adriatic*, exceeded 20,000 grt. The drive for much of this change came from commerce. Britain's position as the world's leading industrialised nation, with an established share of world trade and extensive imperial possessions, despatching goods for export and importing raw materials, possible only by sea, placed the British shipping industry under constant pressure to reduce costs and improve quality. Technological advances themselves were an impetus to the search for further efficiencies to set off against increased fixed costs, which would give other countries the opportunity to develop their own shipbuilding industries.

## End Notes


[1] Sandro Mendonça, *The Evolution of New Combinations. Drivers of English Maritime Engineering Competitiveness during the Nineteenth Century* (Unpublished PhD Thesis, University of Sussex, 2012) p383

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[3] David K Brown, *Warrior to Dreadnought, Warship Design and Development, 1860–1905* (Barnsley, 2010) p67

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1850-1900

# 5 Specialisation shrinks the world

As world trade increased, stimulated by industrialisation in Europe and the US, the steamship rose to the challenge. The general cargo steamer, divided between the tramp ship and the cargo liner, became an increasingly efficient form of transport, as shipowners and shipbuilders worked together to develop vessels with maximum cargo-carrying capacity, minimum fuel consumption and simplicity of operation. The steamship proved flexible and adaptable, with new specialist ship types improving the efficiency of existing trades, such as coal, facilitating the expansion of new ones, such as petroleum oil and frozen food, and speeding the passage of millions of migrants. The steamship also helped to transform international communications, above and below the water. The new technologies were helping to create a new, more interconnected world.

The metal screw steamship revolutionised trade. With more efficient engines consuming less coal, and with iron and then steel hulls that created greater internal space, as well as the ability to offer predictable voyage times, the steamer had innumerable advantages not only for shipowners but also for the merchants and traders she served. Whether the tramp ship seeking cargoes wherever she could, or the cargo liner operating a scheduled service on a fixed route, the general cargo steamer made a huge contribution to the expansion of international trade. These vessels became a crucial link in the quickening pace of globalisation, helping to foster the consumer economy in the developed world, improve the diet of the growing population in industrialised nations and, through facilitating trade and emigration, build the fledgling economies of countries such as Australia, New Zealand, Canada and the US.

The cargo liner emerged gradually as merchants, shippers and importers recognised the advantages of a regular, predictable service. Speed and predictability made the liner the ideal vehicle for carrying passengers, mail and other high value or perishable goods. The range of cargoes carried was many and varied. For example, a Cunard liner returning from the Mediterranean in the 1850s brought back to Britain (from Constantinople) 393 bags of Indian corn, 32 bales of silk, 45 cases of silk, 737 bales of wool and 4,325 kilos of Indian corn; (from Smyrna) one bale of tobacco, 426 bales of madder roots, 189 bags of carmatina and four tubs of leeches; (from Malta) two boxes of honey; and (from Syria) 51 packages of sponges. In 1866 the liner's range was extended to Asia, after Alfred Holt opened up routes to China with his more efficient ships, and then to Australia and New Zealand after the opening of the Suez Canal in 1869. By 1900 the typical cargo liner was a steamship of about 6,000 grt. Serving most parts of the world, the liner accounted for about a third of all British merchant shipping in 1935, and endured until the 1970s.

By then the average liner had doubled in size to about 12,000 tons gross, an increase dwarfed by the size of many other dry-bulk cargo ships. But the constraint upon the cargo liner, with her break-bulk cargo visiting increasingly congested ports with limited cargo-handling gear, was that a bigger ship would have spent more time in port, negating the liner's advantage in providing a regular and speedy service.

The tramp took her name from her itinerant nature. One British shipowner in the 1930s, Robert S Dalgliesh, provided a succinct definition of an unchanging sector: 'We tramp shipowners have to build ships which are wanted in the North Sea one voyage, in the Atlantic the next, then in the Pacific or the Indian Ocean. We have to be prepared to carry any and every cargo'.[1] The tramping trade had begun with the bulk delivery of British coal to the growing network of coaling stations, a vital supply line for the British merchant marine. For the British tramp, coal exports were important, making up the balance of any spare outward-bound cargo capacity, and thus helping to keep freight rates low in a competitive international market.

Just as the more efficient steam engine helped to extend the range of the cargo liner, so it was crucial in enabling the tramp ship to carry bulk freight more cheaply over longer distances. The tramp became 'the instrument in perfecting a number of commodity markets as technological improvements lowered freight costs'.[2] By 1900 tramp steamers accounted for 4.5 million gross tons of total world steamship tonnage of 16.1 million gross tons. By 1914 the steel-hulled tramp steamer, powered by the triple-expansion engine in combination with the Scotch boiler, accounted for 60 per cent of all British tonnage.

The growth of tramp shipping was stimulated by the growing ease with which shipowners could arrange cargoes through agents in overseas ports. This stemmed from the revolution in communications, in which the steamship played a major role, and which helped to create an international tramp market.

Submarine cables were laid soon after the steamship first appeared, with early failures overcome thanks to advances such as coating wires with gutta-percha and the construction of specialised cable-laying vessels. The first submarine cable between Dover and Calais was laid in 1850, followed by the first transatlantic cable in 1856, although this was short-lived and a new cable was laid by Brunel's *Great Eastern* in 1866. By 1900 the globe was linked by some 190,000 miles of underwater cable. Telegrams which had taken a week to travel between the UK and India could now receive a reply in minutes. The result of combining the tramp steamship with a global communications network was closer worldwide commercial interdependence.

Driven by profit and the search for economies of scale, some tramp ship owners began to take advantage of the steamship's great flexibility, to specialise in certain commodities, following the example of the sailing ships, such as the tea clippers and fruit schooners. For most tramp ships, bulk cargoes such as coal, grain and iron ore were their bread and butter business. The typical tramp, for example, was always characterised as the coal and grain vessel heading for the River Plate. As a bulk carrier, the metal steamship was attractive because it was bigger, stronger, faster and more reliable. The steamship's potential was first identified by British coal merchants. Coal became a major export trade for the UK during the nineteenth century, and by 1913 accounted for ten per cent of all British exports. But it was also the fuel that fed British industry and heated the homes of its rising population. For the coal merchant, the steamship could carry more coal more quickly, and it was in the domestic coal trade that the steamship was first tried out as a bulk carrier. In 1841, just two years after the trials of the *Archimedes*, the Bedlington Coal Company built the first iron screw steam collier, the *Bedlington*, which was equipped with its own derrick to lift the coal-filled trucks on board, another advance for its time. The vessel shipped coal from the colliery down the River Blyth to the coal staithes on the River Tyne for loading onto sailing colliers. Although the *Bedlington* lasted only five years, breaking her back as a result of the stresses and strains on her hull, she encouraged further experimentation.

The result was the *John Bowes*, the first truly successful steam collier, built by another colliery owner, Charles Palmer, at his own shipyard in Jarrow. In connecting source to market, speed, space and ease of loading were her big advantages. She had a single 60-foot-long hatch, which allowed her to be loaded directly from the coal chute, although coal trimmers were still needed to stow coal at the ends of the hold and under the side decks. Sailing for London in July 1852, she discharged her load of 650 tons in 24 hours, before returning to the River Tyne, completing each leg of the voyage in 48 hours. One innovation that helped to speed her on her way was the use of sea water as ballast for the return journey, an idea adopted in the 1850s and 1860s as water ballast tanks were developed. Her capital costs were greater than the traditional sailing brig, but in less than a week she had done the work that two brigs could do in a month. It was reckoned that a screw collier could make 30 return voyages between the Rivers Tyne and Thames each year, compared with ten for a sailing collier. Other colliery owners quickly followed her example. Between 1852 and 1854, 36 steam colliers entered service, 'a major financial and technical undertaking for the period'.[3] The steam collier was hugely successful with a steady eight-knot speed. Swift and capacious, designed for ease of operation, she was also robust – the *John Bowes* lasted until 1933, sinking when under the Spanish flag, carrying iron ore. Steam colliers remained in service until the 1960s, when they were still supplying coal to the Thameside cement works. Another important part of their success was that they were part of an integrated supply chain. To make the most of their potential, harbours and loading facilities were improved, mechanised coal drops were introduced, and rail links created between collieries and harbours. The steam collier also accelerated the demise of the sailing ship in the coastal trade as steam coasters took over the movement of both bulk and general cargoes.

Shipping bulk cargoes across the oceans was very different from carrying coal down the coast. Ships had always struggled to carry bulk cargoes safely, their great weight and the tendency to shift posing problems of stability and often causing vessels to roll violently. The solution lay in specially strengthened ships with stronger hulls, combined with central trunking, wing tanks, and engines amidships for greater stability. An early example was the ore carrier *Gellivara* built by the Tyneside yard of Swan Hunter in 1888. In the 1880s, Alexander McDougall designed and patented a whaleback steamer, and these were built at his shipyard in Duluth, Minnesota. The whalebacks had raised turrets to support the accommodation and deck machinery, along with an almost cylindrical hull and flush hatches. In 1892, the first of the new Doxford turret ship design was built by William Doxford and Sons Ltd and named *Turret*. This was followed by a whaleback steamer, the *Sagamore* built by Doxfords under licence from McDougall in 1893. The Doxford turret design reduced the tendency for cargo to shift by incorporating self-trimming devices. Other shipbuilders offered variations of the turret design, but the main designs were restricted under patent. Between 1892 and 1911 Doxfords built 176 turret ships and six more were built by other yards using Doxfords' design.

On the Great Lakes of North America, where shipping iron ore was big business, bulk carriers were developed with an unobstructed cargo space served by multiple transverse hatches which lined up with the loading spouts. All these developments created a robust vessel which, combined with other technological developments, became increasingly efficient, helping to reduce the cost of ocean transport.

One of the major new trades of the late nineteenth century was petroleum oil. In the early days of the industry, following the sinking of the first oil well in 1859, petroleum was shipped in barrels and cases or cans on board sailing vessels. As demand rose, this would become costly and inefficient, but several early attempts to develop bulk tankers failed. The prototypes were premature, the trade was too small, and there was a lack of supporting infrastructure. In 1863 three purpose built oil carriers, the *Ramsey*, the *Atlantic* and the *Great Western*, were constructed under special survey to LR class A1. The *Ramsey* had a capacity of some 1,400 tons of petroleum. They were all iron-hulled sailing ships; the latter two, designed for the Atlantic oil trade and built on the River Tyne, had their tank space sub-divided by central longitudinal and transverse bulkheads with their masts serving as expansion trunks for the tanks, but none of the vessels were used for their intended purpose. In 1872 the first ocean-going steam tanker, the *Vaderland*, was built to LR class by Palmer's in Jarrow for the Belgian Red Star Line. Bulk transportation had become viable with the development of large tank farms on the oilfields, but ports were slow to follow suit. The *Vaderland* and her sisters, the *Nederland* and the *Switzerland*, were never used as tankers, in part because of the inadequate facilities of Antwerp, their home port. Another reason for their change of use from tankers was the plan to include passenger accommodation, which was deemed unsafe alongside oil. They were used instead for transporting dry cargo and passengers, and as such contributed little to the development of tanker design.

The first successful steam oil tanker was the *Zoroaster,* built in 1878, notable as the first to actually be used as such and to burn oil fuel. She was the idea of Robert and Ludvig Nobel, the entrepreneurs opening up the oilfields in Baku on the Caspian Sea. As production increased, the brothers were confronted with problems of storage, transportation and distribution. Wooden barrels were inadequate, expensive, leaky and hazardous. The Nobel Brothers' solution was to pipe the oil directly into tanks in a specially constructed ship designed to navigate the Caspian Sea and the Volga River, from where the oil could be distributed across Russia. The *Zoroaster,* built with two iron tanks in her steel hull, was the first of a fleet of similar vessels – within four years of the delivery of the *Zoroaster,* the Nobel Brothers' fleet had grown to include 12 tank steamers for use on the Caspian Sea. Even so, the *Zoroaster*'s cargo was only 242 tons, and by the mid-1880s, 90 per cent of all transoceanic oil shipments were still made in parcels of small containers or cans rather than in bulk.

# The Thames Ironworks and Shipbuilding Company

The Thames Ironworks and Shipbuilding Company, one of the largest shipbuilders in London during the nineteenth century, originated in 1837 as Ditchburn and Mare Shipbuilding Company. During its first nine years of business, Ditchburn and Mare built the *Erin* and the *Ariel* for P&O, and in 1846, one of the world's first iron warships, HMS *Recruit*, for the Royal Navy. When Ditchburn retired in 1847, Mare renamed the business C J Mare & Company. The rapidly growing company purchased land by the River Lea near Canning Town and their success was evident in the building of P&O's *Himalaya*, then the world's largest passenger ship. In 1854, Mare also provided the iron for Brunel's Royal Albert Bridge over the River Tamar.

Despite Mare & Co's growing client list, Mare was declared bankrupt due to poor financial decisions and growing competition and his father-in-law, Peter Rolt, kept the company solvent. In 1857, Rolt transferred the company's assets into a new limited company – the Thames Ironworks and Shipbuilding Company Ltd, and he became Chairman and a major shareholder.

The company was the largest shipbuilder on the Thames, with a main quay 1,050 feet long. *Mechanics' Magazine* described the production sites as 'Leviathan Workshops'. In 1860, the company built HMS *Warrior*, now a museum at Portsmouth. It was the first iron-hulled armoured frigate and the world's largest warship, with a displacement of over 9,000 tons. The works flourished despite the financial crisis of 1866, having specialised in warship production as well as passenger liners, producing warships for Austria, Denmark, Greece, Germany, Japan, Romania, Portugal, Russia, Spain and Turkey and lifeboats for the Royal National Lifeboat Institution.

During the late 1890s, the philanthropist Arnold Hills became Managing Director. Popular with his employees, he proposed a reduction to an 8-hour working day. He endeavoured to create a community within the company and set up the Thames Ironworks Football Club in 1895, which would later become West Ham United. The crossed hammers on their badge represent the origins of the club.

On 21 June 1898, tragedy struck at the launch of HMS *Albion*. Christened by the Duchess of York, Princess Mary of Teck, and watched by thousands, the fast launching of the ship created a huge wave that swept onlookers into Bow Creek, killing 38. Hills, devastated by the accident, paid for the funerals and visited each victim's family.

Four years later, Thames Ironworks merged with John Penn & Sons. The combined company only lasted 13 years, closing on 21 December 1912, a year after the launch of their last ship HMS *Thunderer*.

It was the experience of the Nobel Brothers' fleet that informed the next stage in the development of the tanker. They shared their information with a British shipbuilder, Henry Frederick Swan, who discussed with them the improvements they would like to see in a new generation of tankers. The new vessel was launched on 16 June 1886. Classed by Bureau Veritas (BV), she incorporated a number of innovative features:

> *'Oil was to be carried right out to the shell; provision was made to carry water ballast on the return voyage; cofferdams were fitted at each end of the cargo tank section; the cargo valves could all be operated from the main deck; the cargo main was carried through the cargo tanks, just above the floors; vapour lines were fitted at the top of each expansion tank; cargo pumps for loading and discharging were fitted below main deck level and finally, countersunk riveting was used on all oil-tight bulkheads.'*[4]

She had been designed by Swan and built by Armstrong Mitchell on a speculative basis but her advantages were evident to those in the trade; she was soon snapped up by the German agent for the American Standard Oil Company, who named her *Glückauf*, and placed several further orders. A second tanker was launched the day after *Glückauf*, named the *Bakuin*, this time classed by LR and built by William Gray of West Hartlepool. She too proved a success, in constant service until she was destroyed by fire in 1902. The timing of the *Glückauf* and the *Bakuin* was opportune, taking advantage of a rising tide of demand. The number of ships engaged in the oceanic oil trade rose from less than a dozen in 1886 to nearly 80 five years later, each carrying between two and four thousand tons of oil in bulk from the oilfields in the US or Russia to ports in Europe.

The tanker posed all sorts of questions for naval architects, and Benjamin Martell, the Chief Surveyor of LR, delivered papers on tanker design to the Institution of Naval Architects (INA) in 1886 and 1894. Entrepreneurs proved inventive in overcoming obstacles to financial gain.

When Marcus Samuel, who later founded the Shell Transport and Trading Company in 1897, engaged in a joint venture with the shipbroker Fred Lane in the 1880s to sell Russian oil in Asia, they were determined to use the shorter route via the Suez Canal rather than the usual route around the Cape. But they had to overcome the anxieties of the Suez Canal authorities about the dangers posed by oil tankers; design errors and operational mistakes had caused a number of losses among early tankers and the carriage of oil in bulk through the Canal was banned. The *Murex*, built in 1892 by William Gray of West Hartlepool, took advantage of the recently developed system of water ballast, with tanks which could be easily discharged to float off the vessel should she run aground. This met the concerns of the Canal authorities, and in the same year the *Murex*, carrying 4,000 tons of oil, became the first oil tanker to sail through the Canal. This was the beginning of the Canal's crucial role as a conduit for oil, which would become even more important once oilfields in the Middle East were opened up. Samuel also had the foresight to develop port facilities in advance of his new venture in Batavia, Singapore, Bangkok, Hong Kong, Shanghai and Kobe.

The role of the steamship as a vital link between source and markets was highlighted in the way it bridged the gap between the abundant agricultural commodities available from distant pastoral economies and the growing urban populations of industrial economies. By the mid-nineteenth century, the main foodstuffs transported over long distances at sea were grain and expensive dried fruits and exotic spices. Canned food was available, and by 1869 manufacturers in Queensland were exporting more than a million kilograms of canned meat every year. But it was still regarded as something of a novelty and was certainly too expensive for working class families. Dr Brown, the author of *The Food of the People* in 1865 wrote that 'The plague spot, the skeleton in the closet of England, is that her people are underfed'.[5] The challenge was connecting the hungry in England and elsewhere with the ample produce of countries like Australia, New Zealand and Argentina.

One half of the solution lay in an effective refrigeration system, which inventors had been striving without success to perfect throughout the first half of the nineteenth century. The opening of the world's first freezing works in Sydney in 1861, and the realisation of the potential profits to be made from exporting the meat surpluses of the southern hemisphere, encouraged further research. The other half of the solution lay in extending the reach of the steamship over the longest trade routes, and this had been accomplished by 1879, when the first direct steamship voyages were made from Europe to Australia and New Zealand.

It was the Argentines who took the lead, recognising the potential of refrigeration for their own agricultural produce. They sponsored a French engineer, Charles Tellier, whose work on refrigeration from 1859 led to the first shipment of beef from Montevideo to London on the *City of Rio de Janeiro* in 1868. This failed because the refrigeration plant broke down. A second attempt took place in 1876, using an ammonia machine on board the sailing vessel *Frigorifique*, but this also failed to keep the meat in good condition. An alternative method, developed by another French engineer, Ferdinand Carré, and tested on board the Argentine steamer *Paraguay* in 1878 on a voyage from Buenos Aires to Le Havre, proved successful but failed to attract further orders. It was only in 1883 that the first regular shipments from Argentina took place, on Houlder Brothers' steamship *Meath*, specially fitted out with refrigerating machinery for the voyage.

In the meantime chilled meat had been shipped from the US to the UK, starting in 1877, but the process was flawed and expensive. Another system, the Bell–Coleman, was trialled on board Anchor Line's LR-classed *Circassia*, which in 1879 became the first mechanically refrigerated vessel to cross the Atlantic.

Several earlier attempts to send frozen meat from Australia to the UK, such as the voyage of the steamship *Norfolk* in 1873, had also been failures. But a group of Australian businessmen, spurred on by the results of the *Paraguay* voyage and impressed by the Bell–Coleman system, installed the latter on board the LR-classed chartered steamer, the *Strathleven*, which arrived in London in early 1880 with a cargo of frozen Australian beef and mutton in good condition. The first cargo of frozen Australian butter followed, in 1881, by which time the obvious potential of the frozen meat trade had led a group of Australian farmers to convince the Orient Line to begin the first regular service, with the Line installing special equipment on board three of its liners. The first, originally designed specifically for the Australian mail trade, was the *Orient* – she was classed ✠100A1 by LR and equipped with refrigeration equipment in 1882. Completed in 1879 by John Elder & Co., Glasgow, at 5,386 tons gross and with a length of 445.6 feet she was the largest ship in the world other than the *Great Eastern*, 19 years her senior and with a length of 679.6 feet and 18,915 tons gross. *Orient* was constructed of iron, with two funnels and four masts rigged for sail; her machinery was specially surveyed by LR during construction and with a single screw propeller she could reach a speed of 15 knots.

After a visit to Australia to learn about the trade, a New Zealand businessman made a similar approach to the Albion Line, and the first cargo of frozen New Zealand lamb was despatched to London on board the Albion Line's *Dunedin*, also classed by LR, in 1882. Within a couple of years there were two regular fortnightly services, the second operated by the New Zealand Shipping Company, which had ordered five specially equipped steamers for the purpose. A flourishing New Zealand meat freezing industry was the result, and by 1914 the country had 31 freezing plants. As one commentator, David Jones, later remarked, 'Refrigeration has revolutionised the agricultural and pastoral industry in New Zealand, and the extent to which the industry has contributed to the prosperity of the Dominion cannot be exaggerated'.[6]

As ammonia refrigeration systems became more efficient, the cost of carrying frozen meat fell, and the volume of meat exports rose. Ships purpose-built for the trade appeared, such as Turnbull, Martin & Co.'s *Elderslie* of 1884; for her, unlike most other cargo steamers, speed, to avoid deterioration in the cargoes, was a priority. Even in those early years, reliability was high; for instance, out of 172 shipments made from South America between the years 1882 and 1887, only nine were rejected. Even so it was a novel trade that caused some concern among London insurers, who turned to LR for reassurance, leading the Society to issue the first *Rules for Refrigerating Machinery* in 1898 and appoint its first specialist refrigeration surveyor, Engineer Surveyor Robert Balfour. In the same year the first Refrigerating Machinery Certificate was issued by LR for the steamer *Wakool* and she was denoted as ✠RMC in the *Register Book*. By 1914, 40 per cent of meat consumed in the UK was imported. The success of the trade stimulated the extension of refrigeration to other produce, including apples and bananas, making fruit available out of season, and later eggs and shellfish. The rate at which some of these trades increased was rapid; for instance, exports of Australian butter leapt from 4 million lbs in 1891 to 35 million lbs a decade later. But despite its success, it remained a highly specialised trade, with around 200 refrigerated vessels in service by 1912.

In this field as in many others, by making more food widely available at cheaper prices to the populations in Europe, the steamship was shrinking the world. It was also a catalyst for the economic transformation of pastoral nations in Australasia and South America, as other meat producers invested in freezing plants near main stock-rearing areas, and cold stores were constructed at major ports. Without the steamship, none of this would have been possible.

Carrying millions of European migrants, the steamship as a passenger carrier also made a significant contribution to the economic and cultural development of countries in North and South America, Australasia and Asia. Between 1815 and 1930, 56 million Europeans migrated overseas. Most of them (33 million) travelled to the US, but significant numbers settled in other nations: 6.5 million in Argentina, 5 million in Canada, 4.4 million in Brazil and 3.4 million in Australia. While the numbers moving before 1850 had been significant, especially the more than a million people escaping poverty and hunger in Ireland between 1846 and 1851, the peak flow before 1914 occurred after 1880, when 900,000 people migrated every year from the countries of their birth. They all travelled by sea. The miserable and squalid experience endured by many on board sailing ships had prompted some of the earliest legislation regulating shipping, such as the US Passenger Act of 1848. The steamship helped to transform the experience for migrants, making the process cheaper, easier, faster, with more passengers per voyage on scheduled services and, even in steerage, providing a much more comfortable passage. Competition between lines brought better facilities and discounted fares, although there was little movement in the real value of average fares between 1850 and 1910. Cunard's steerage fares, for instance, averaged just under £3 10s per passenger from 1885 to 1899, and just under £5 from 1899 until 1914. In 1883 a group of four adults and one child paid $72 to travel from Bremen to New York with Norddeutscher Lloyd, while in 1903 the passage from Londonderry, Ireland, to Rochester in Pennsylvania, including inland fares, cost $75 for two adults and one infant.[7]

Many lines operated specialist ships purpose-built for the market, such as the *Thingvalla* operated by the Thingvalla Company of Copenhagen, built in 1875 to carry migrants to the US. The contribution made by the passenger lines may be gauged from the fact that the Holland-America Line, founded in 1873, had carried nearly half a million people to the US by 1898.

The transatlantic passenger liners, the sovereigns of the seas, also carried their fair share of migrants. They also offered travel in unparalleled luxury for those who could afford it. Sailing vessels had long been equipped with skylights but in the transatlantic liners of the 1880s this was developed into a major design attraction, with a dome over the main saloon. Over the years this increased steadily in size, with the main public rooms often extending through two 'tween decks. The LR classed sister-ships *Campania* and *Lucania* of the 1890s epitomised the growing power and magnificence of these ships, with twin five-cylinder triple-expansion engines generating 21 knots, and long dining saloons lit by electric light. For these Cunard vessels, speed was as important as size, and the best of them came to signify national prestige, competing against each other for the Blue Riband for the fastest crossing.

The comfort of the steamship, and its extended voyage patterns, led to the innovation of the cruise holiday. In 1844 P&O began its first cruises to the Mediterranean, operated by commercial vessels carrying passengers, with sightseeing arrangements in port.

In 1845 the Hamburg shipowner Robert Miles Sloman was offering a world cruise by sailing ship. The start of modern cruising has been attributed to the directors of the North of Scotland, Orkney and Shetland Steam Navigation Company, who offered cruises to Norway and the Baltic from Aberdeen, starting in 1886 with the *St. Rognvald* and followed for the 1887 season by the *St. Sunniva*, the world's first purpose-built cruise ship, which was a great success.

In 1889 Orient Line and Pacific Steam Navigation began running liners redeployed from their Australian runs to seasonal cruises in the fjords. Further similar cruises followed, to the Mediterranean from 1893 and the West Indies from 1895. This template was taken up by many other liner companies.

All these ships, from the general cargo steamer, the cargo tramps and the cargo liners, to their specialist offshoots, the ore carriers, oil tankers and refrigerated cargo carriers, played a central role in the steady move towards global economic integration. The new technologies, speeding up communications, increasing the capacity to carry people and goods, and offering predictable services, helped consumers and producers to enhance the way they did business. The transportation of raw materials and finished goods across the globe, as well as underwater cables, overseas mail and mass European migration, all helped to cement the international communications that furthered economic growth and integration.

## End Notes

[1] Robert S Dalgliesh (discussion) as cited in W Stanley Hinde, 'The Ocean-Going Tramp Steamer from the Owner's Point of View', *Transactions of the North East Coast Institution of Engineers and Shipbuilders*, 47, 1930–1931 (Newcastle Upon Tyne, 1931) p55

[2] Robin Craig, *British Tramp Shipping, 1750–1914* (St John's, Newfoundland, 2003) p32

[3] J A MacRae & C V Waine, *The Steam Colliers* (Albrighton, 1990) p15

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1850-1900

# 6 Science, standards and safety

The contribution of eminent theorists, most notably William Froude, had a lasting impact on the industry. Theories of thermodynamics and hydrodynamics, as well as research into stability and structures, helped to make ships safer and more efficient. The world's navies led the way in applying this body of work, while the mercantile marine, conservative in approach, operating slow cargo ships fuelled by cheap coal, tended to lag behind. The work of a relatively small group of leading marine engineers and naval architects fostered the growth of professional societies, which became increasingly influential. Their technical discussions reinforced the move towards a more scientific and analytical approach in ship design and construction; they helped to foster the spread of knowledge and best practice nationally and internationally; and they promoted higher standards of industrial education. The growth of world shipping, and the impact of technological change, compelled nation states to begin cooperating on an international scale in order to regulate the industry. In the absence of state regulation in the early nineteenth century, however, the classification societies had been instrumental in assimilating technological change in order to deliver guidelines that enhanced standards of construction and the safe operation of ships at sea.

Before 1900 the evolution of the modern steamship owed much, according to maritime historian David Starkey, to 'the inspired tinkerer'.[1] Application preceded analysis, the inventor worked in isolation, there was little formal research and development, and shipowners and shipbuilders, driven by commercial considerations, played a waiting game as far as new technology was concerned. Yet this process had a worldwide and revolutionary impact. More than that, the gradual accumulation of data, and its diffusion as the new technologies developed, although stemming from an empirical rather than a scientific approach, enabled a new generation of engineers and naval architects. Men like Brunel, Scott Russell, and Froude developed new theories new theories and more rigorous processes for dealing with other criteria for structural strength, stability and ship resistance, in turn transforming the nature of naval architecture itself. This in itself was part of the great march of science that accelerated during the second half of the nineteenth century, as it developed into a discrete intellectual concept, accepted by the expanding bodies of professional engineers and naval architects.

At the start of this period, ship design and shipbuilding owed little to scientific knowledge. A Society for the Improvement of Naval Architecture existed briefly in London, from 1791 to 1798, yet despite this, in 1897, Sir Edward Reed, the renowned naval architect, looking back at naval architecture in 1860, observed that 'its advancement, in all the generations that had gone before, had not carried it beyond the grasp of an individual, or the compass of a single discourse'.[2] By comparison with the first half of the century, naval architecture developed rapidly after 1850. In France, Frédéric Reech, head of the École du Génie Maritime in Paris from 1852, seen by Scott Russell as 'probably the man in the whole world most profoundly conversant with the whole mathematics and mechanics of naval architecture',[3] described the theory behind Froude's *Law of Comparison* – but it never found practical application and Froude himself was completely unaware of it. Alexei Krylov, born in 1863, was an outstanding Russian naval architect, quickly establishing an international reputation. Two papers he presented to the Institution of Naval Architects (INA) in the 1890s on the behaviour of ships in the seaway gained him the INA Gold Medal, of which he was the first overseas recipient. Reed confessed that in reviewing all this progress, he was 'overwhelmed with the magnitude and merit of the aggregate of what has been accomplished since 1860'.[4]

In Britain the way was led by William Rankine, Professor of Civil Engineering at Glasgow University from 1855 until his death in 1872. He introduced thermodynamics, so important for improving the power and efficiency of steam engines, to marine engineers, writing the first textbook on the theory, *A Manual of the Steam Engine and Other Prime Movers*, in 1859. Five years earlier William Thomson had been the first to formulate a precise definition of the subject. During the 1850s the work of Rankine, Thomson and the German physicist Rudolf Clausius had also led to the emergence of the first and second laws of thermodynamics. Following research in conjunction with Thomson and James Napier on propulsive power, Rankine's second major contribution to naval science came in the 1860s with his streamline theory, a landmark in the development of modern ship hydrodynamics or the theory of ship propulsive power. Frank Purvis, who designed ships for William Denny & Brothers in the 1880s, described Rankine's work as 'something tangible, something from which one can, without any data derived from previous ships, calculate on first principles the speed of a ship for a given horse-power, or conversely the horse-power of a ship for a given speed'.[5]

The greatest influence on ship design was William Froude. As one naval architect, David Brown, recently emphasised, 'No one has done more to increase the understanding of a ship's behaviour'.[6] Having left Oxford with a first-class degree in mathematics, Froude gained engineering experience on the South Eastern Railway and then with Brunel on the Bristol and Exeter Railway. When Brunel was concerned about how the *Great Eastern* would behave at sea, he asked Froude to investigate the impact of rolling on ships. Little work had been done on the subject for many years, and most of the conclusions previously reached were erroneous.

Working alongside another member of Brunel's staff, William Bell, who conducted model tank tests, Froude developed his *Theory of the Rolling of Ships*, presented to the INA in 1861. William White, one of the leading naval architects of the late nineteenth century, would write that while Froude's theory was not intended to cover every aspect of the problem, 'it far more completely represents those conditions than any theory which preceded it, and has exercised a great and beneficial effect upon ship designs'.[7]

Even so, many were sceptical about Froude's theories. As an early member of the INA, Froude experienced the antipathy of the INA's associate members, mainly naval officers, who frequently criticised the more analytical stance taken by the small body of full members. The favourite tack they took towards any technical views they disliked was to insist that certain points came down to practical seamanship. Yet there was a seam of enlightenment within the Admiralty, and following criticism of educational standards from Scott Russell and others, the Admiralty responded by re-founding the School of Naval Architecture in South Kensington in 1864. The results of fostering a more technical approach to design and construction through the revived school would prove influential in later years, when the Admiralty would be in the vanguard of adopting steel, the water-tube boiler and the steam turbine. With the formation in 1883 of the Royal Corps of Naval Constructors, based on the French Corps de Génie Maritime, the Royal Navy also created a structured system of advancement for professional naval architects.

Yet it was only the disaster of HMS *Captain* that alerted the Admiralty to the importance of Froude's work on stability. A privately built, poorly designed warship that was overweight and of low freeboard, HMS *Captain* capsized with the loss of 490 lives in 1870. Froude had also concluded that bilge keels were an effective way of limiting the rolling of ships in heavy seas, which led the Admiralty to adopt them for every ship in the Royal Navy. Froude also experimented with an early form of tank stabiliser, inspiring other engineers to undertake their own experiments. However, it was not until 1911 that the first successful tank stabiliser was developed, when the German Frahm system was fitted to the Cunard liner *Laconia*, reducing rolling by as much as 60 per cent. A Scottish engineer, Andrew Wilson, had patented a fin stabiliser in 1898, but although his design held the seed of the idea that was to be adopted, this remained undeveloped for another 30 years.

The first ships to use activated fin stabilisers were built in Japan to the design of Dr Shintaro Motora, but failed to be a success due only to the cumbersome operating mechanisms. In 1936 Sir William Wallace patented an activated fin stabiliser with modern gyro control and electro-hydraulic mechanism, and by 1955 there were 148 versions of activated fin stabilisers at sea, including on naval vessels.

In 1865 Froude had also begun investigating the resistance of ships on moving through water. In 1867 he towed two different experimental hull shapes, which he called *Swan* and *Raven*, behind a steam launch on the River Dart in Devon, to test whether there was any difference in the drag they incurred. These tests were hugely significant. First, they showed there was no general ideal hull form for all ships, since the two models performed best at different speeds. Second, Froude used the data to develop his *Law of Comparison*, succeeding where others had failed in accurately predicting the performance of full-scale vessels from the results of model tests. Froude's work provided the basis for others to further refine his theory, such as the German engineer Ludwig Prandtl, whose *Boundary Layer Theory* in 1904 defined the flow behaviour of a viscous fluid near a solid boundary.

Hydrodynamics now became a central part of design for more demanding ships. While estimates for the power of a new ship, based on experience, had proved sufficiently accurate for ships of similar size and propulsion, they were proving much less accurate for vessels divergent from their predecessors with, consequently, an adverse impact on speed, fuel consumption and performance.

Froude's law allowed naval architects to calculate the optimum balance between a vessel's power and fuel consumption for any given speed. It was a great advance. In addition, Froude's law could also be used to produce hull shapes refined by model tests that were fast and handled well.

Froude wrote to Sir Edward Reed, the Chief Constructor of the Navy on 24 April 1868, proposing the construction of an experimental tank and proposing a two-year research programme. In February 1870, the Admiralty approved £2,000 for the building of the tank in the grounds of Froude's house, Chelston Cross, in Torquay. The first experiments took place in 1872, enabling naval architects to test the efficiency of new hull shapes and develop shapes of least resistance, resulting in faster, more economical ships. Froude's work on model testing still forms the basis of tank testing today, while the Torquay tank has been described by Oosterveld as 'the first scientific industrial service centre in the field of marine technology'.[8]

Other navies also appreciated Froude's contribution to ship design. In 1874 Bruno Tiedeman, Chief Constructor of the Dutch Navy, used Froude's theories to predict the engine power of a new warship and, with Froude's advice, went on to establish a model test tank in Amsterdam. All Italian warships after 1890 were designed according to Froude's theories as were many warships built for the Imperial Japanese Navy, many of which were built in the UK.

Although there was less enthusiasm for his work among commercial shipbuilders, Froude had his admirers; John Scott Russell, reflecting on the work of Froude and others in 1874, asserted that 'we are now coming to the culminating days of science, when it is not only believed in, but acted upon'.[9] John Inglis of Glasgow presented the results of his method of analysis based on Froude's *Law of Comparison* to the INA in 1877. William Denny, one of the leading UK shipbuilders, witnessed the early Torquay experiments, which led him to use the tank to provide data to compare with the results of sea trials for one of his new ships, the *Merkara*. In 1883 Denny built the world's first commercial test tank, the Denny Tank, which still exists, at his Dumbarton shipyard on the banks of the River Clyde in Scotland. His Chief Designer, Frank Purvis, moved to Japan to become a Professor of Naval Architecture, where he helped to set up a model test tank in Nagasaki. Two other major British shipbuilders, John Brown and Vickers–Armstrongs, also built their own test tanks in 1904 and 1910 respectively, recognising it was no longer satisfactory to guess the requirements for the superliners of the day. At the other end of the scale, the consulting naval architect George Watson incorporated Froude's laws governing least resistance into yacht design, producing the most successful yachts seen in British waters for decades. Froude's work also inspired others to establish test tanks overseas. Before the end of the century, tanks had been built at La Spezia in Italy (1889), Dresden in Germany (1892), St Petersburg in Russia (1894) and Washington in the US (1898); while the first decade of the new century saw more tanks built in Germany, France, the USA and Japan.

Froude himself was unsurprised at the lack of regard for his work among most commercial shipbuilders. He had commented in 1872 how most shipbuilding, even by reputable builders, still depended on rule of thumb. R W L Gawn, writing in 1941 about the ad hoc way in which shipyards were experimenting with new designs for the screw propeller, noted how an observer in the 1860s had described how many of them were full of 'piles of funny looking castings of all shapes and sizes, the produce of an incipient design'.[10] Many British shipyards, building smaller ships, also found testing tanks expensive, preferring to copy designs emerging from those who had used them. Another deterrent to adopting Froude's work was the fiendish complexity of the calculations necessary to compute stability at large angles of heel.

It was only in 1878 that this complexity was eased, to a degree, by two inventions: an advanced calculating machine, the mechanical integrator, attributed to the Scottish engineer James Thomson, younger brother of William, later Lord Kelvin; and the cylindrical slide rule, invented by George Fuller, Professor of Civil Engineering at Queen's College, Belfast, which gave an additional decimal place compared with conventional slide rules. The mechanical integrator was a complicated machine, which in tracing the perimeter of a shape also moved a measuring device. By calculating the surface area of a hull cross-section, it provided the engineer with information about the ship's capacity and centre of gravity.

The response of shipbuilders to these developments was summed up by historian David Pollock in 1884: 'The part taken by merchant shipbuilders has consisted in the experimental verification, and sometimes the practical correction of principles thus evolved, but even to this extent the service done has been largely incidental'.[11] Since many of them were building general cargo ships, where speed was less important, minimising resistance and improving propulsion were not a high priority when engines were relatively efficient and coal was cheap. This absence of enthusiasm became apparent when an appeal to shipbuilders for funds towards a national testing tank in the UK fell mainly on deaf ears. The principal – and most generous – exception was Alfred Yarrow, who had always been receptive to the application of science in ship design and construction particularly for his fast torpedo boats, and the tank was built at the National Physical Laboratory at Teddington in 1911.

Many British shipbuilders had little regard for education. There was value in experience, as there always had been, and in-service experience helped ship designers to make repeated improvements. Andrew Betts Brown, the Scottish marine engineer who invented the telemotor, constantly refined his designs thanks to the advice he sought from ships' captains, whom he referred to as 'these difficult-to-please gentlemen without whose fault-finding no advances would have been made.'[12] But few shipbuilders or engineers sent their apprentices to the re-founded naval school, whose illustrious lecturers included John Scott Russell as well as two other eminent naval architects, Edward Reed and Nathaniel Barnaby, and two leading theorists, William Rankine and William Froude. When the school merged with the Royal Naval College in Greenwich in 1873, William White's lectures attracted students from navies around the world, yet hardly any came from British shipyards or the British merchant navy. While students from the College would provide many navies around the world with a highly trained core of constructors, barely a handful found positions in British commercial shipyards. Among the exceptions was Sir John Biles, who worked for J & G Thomson on Clydebank in the 1880s. On the other hand, many talented former students would eventually find places as surveyors for LR.

In the shipyards belief in the apprenticeship system remained unshakeable. Rather than waste three years at the Royal Naval College, students could pick up technical training in the yard and at night school. By the early 1870s, apprentices in the north-east of England were attending classes in mechanical drawing given by the Chief Draughtsman of a local marine engineering works. But many local yards also had at least one draughtsman recruited from overseas, since the standard of their scientific education was much higher than in the UK.

William Denny, one of the most progressive shipbuilders of his day, was well aware of this deficiency. His own father, Peter Denny, himself a wealthy shipbuilder, had refused to send William to university, and his son never forgot it. One of the few shipbuilders to become an active member of the INA before the 1880s, William became an ardent advocate of higher educational standards in the industry. Standards did begin to rise, leading eventually in major shipbuilding areas to local technical colleges offering courses that included naval architecture.

# William Denny & Brothers (1811–1963)

William Denny was a Scottish shipbuilder who formed a partnership in Dumbarton with Archibald McLachlan to build early steamships.

After William Denny's death, three of his sons – William Jr., Alexander and Peter – formed a partnership called Denny Brothers, founded in 1844. Prior to the partnership, all three brothers had worked at shipyards. By 1845, the brothers moved back to Dumbarton, renting Kirk Yard on the banks of the River Leven. This decision proved to be a lifeline for Dumbarton and its industry.

Only a few months after moving into the new yard the company leased their father's old wood yard. During this period, the company had a capital of £800 and employed 14 men. Soon after, two other Denny sons, John and James, joined the company.

In 1849, Denny Brothers was dissolved, and a new company was formed, William Denny and Brothers and the company moved to a new shipyard on the east bank of the Leven. They became well-known shipbuilders and by 1851, the company employed over 350 men.

The company worked with the marine engineering business Tulloch and Denny, which was run by Peter Denny, John McAusland and John Tulloch; it provided gears and parts for William Denny and Brothers. In 1854, William Denny Jr. died aged 38, leaving Peter Denny in charge of William Denny and Brothers.

In 1862, James Denny and John Tulloch retired, and Peter took charge of Tulloch & Denny. As Tulloch was no longer involved with the company, Denny renamed the engine works Denny and Co. By 1865, William Denny and Brothers were one of the biggest shipbuilders in Scotland. Peter Denny then made his son William (1847–1887) a partner in the company in 1868.

William was interested in hull forms and published several papers on the subject throughout the 1870s and 1880s. He persuaded his father to fund the first commercial test tank at Dumbarton, which remained in use until the closure of the yard in 1963.

In 1870, the shipbuilders Scott and Linton went bankrupt, and companies were looking for other shipbuilders to complete their projects. William Denny and Brothers was commissioned to rig the *Cutty Sark*; which was ready to sail in just 12 weeks.

In total the company built over 1,500 ships, notably the first all steel merchant ship, *Rotomahana* (1878) and *King Edward* (1901), the first commercial ship to be driven by steam turbines. After the Second World War, Denny and Brothers continued to grow, and manufactured several ferries and early ro-ros.

By 1961, William Denny and Brothers employed over 1,800 people. Despite their potential to become one of the largest shipbuilders of the twenty-first century, the company's unsuccessful attempts to compete with other shipbuilders meant they went into voluntary liquidation in 1963.

The subject was also slowly gaining ground in universities, with the widow of John Elder founding the first Chair in Naval Architecture at Glasgow University in 1883, followed by a second at the College of Physical Science (later Armstrong College) in Newcastle in 1891. The latter came about partly at the instigation of the local institution of engineers and shipbuilders, and the first post-holder was Robert Weighton, the Chief Draughtsman at R & W Hawthorn Leslie and Co. Ltd. on Tyneside.

For most UK shipbuilders, however, the favoured route for their apprentices remained part-time study at evening classes, despite criticism that courses were too short. It was also suggested that students became overtired at the end of a long working day, although long hours also brought in much-needed income to often poor households. In 1877 the General Committee of LR made a grant towards the maintenance of two students at the Royal School of Naval Architecture and Marine Engineering at Greenwich, one in each discipline, and this led to the creation of an annual scholarship in 1878. This enlightened but self-interested act came when the science of naval engineering was still in its infancy, and the Society recognised the need for well-qualified young men knowledgeable in the developing technologies of the time. By 1914 there were also three scholarships in Naval Architecture at Glasgow University, three at Armstrong College (University of Durham in Newcastle) and another three at Liverpool University, as well as three in Marine Engineering for students nominated by the Institute of Marine Engineers.

The diffusion of knowledge and experience, described by William Armstrong as 'that commerce of ideas by which wealth and knowledge are augmented',[13] was critical for the transition of an invention from innovation to proven technology. William Rankine had set an example with his textbook, *A Manual of the Steam Engine and Other Prime Movers*, in 1859, reaching out to a far greater audience, and proving an inspiration to a rising generation of engineers. Scott Russell's remarkable three-volume work, *The Modern System of Naval Architecture*, published in 1865, might have had the same impact but for its elephant-size format, limited print run and high price; it cost 40 guineas (£42) or four months' wages for a ship's draughtsman. More effective was *Shipbuilding, Theoretical and Practical* in 1866. Rankine was one of the contributors, and in the preface he described how the work aimed to be a complete guide to the scientific principles of shipbuilding 'at a price within the means of the general body of practical men' and 'in as plain and clear a manner as possible'. It was an approach supported by William Denny, who wrote to Froude in 1873 that there was a need for 'permeating us practical men with the intelligence of those above us'.[14] Denny himself was eager to deepen the understanding of ships' captains and shipowners about ship science, and from 1884, every vessel that left his yard was furnished with a handbook of its technical properties. William White's *Manual of Naval Architecture*, first issued in 1877 as a textbook for officers of the Royal Navy, reached even further afield, being translated into German, French, Italian and Russian. One reviewer remarked that no other work in English supplied the information required in such straightforward language, and expressed the hope it might have an impact on the still considerable ignorance about the new science of naval architecture among sailors, shipowners and shipbuilders.

Knowledge was spread by the rising number of professional bodies. Members of one were often members of another, helping to disseminate ideas and information. Among the new bodies was the Institution of Mechanical Engineers (IMechE), founded in Birmingham in 1847, which elected several distinguished marine engineers as Presidents during this period, including William Fairbairn (1854–1855), John Penn (1858–1859 and 1867–1868), William Armstrong (1861, 1862 and 1869) and Robert Napier (1863–1865).

In 1889, the Institution also set up a Marine Engine Trials Committee, publishing the results of subsequent research. In 1860 the very fact of the foundation of the Institution of Naval Architects (INA) as a specialist branch of the engineering profession indicated the progress the movement towards scientific analysis was starting to make in the industry. It was John Scott Russell's idea, and the small band attending the inaugural meeting included LR's Joint Principal Surveyors, James Martin and Joseph Horatio Ritchie. The INA was the internet forum of its age, challenging the received wisdom of the day. From the start it set out to be a broad church, with the aims of sharing best practice through published papers, promoting 'the science and art' of shipbuilding, examining new inventions and investigating professional matters. But it took until the mid-1880s for full professional members, those at the forefront of the cause, to outnumber their more conservative brethren, the associate members, and for the INA to break free from the influence of the Admiralty.

Similarly, the Institute of Marine Engineers (IMarE now IMarEST), founded in 1888 with the intention of raising the status of steamship engineers, also aimed to share best practice and develop a body of technical knowledge. This was primarily to help members keep up with the pace of technological change, such as 'the increasing boiler pressures and engine speeds, the demand for economy in fuel consumption, the special machinery fitted for the greater comfort of passengers, and for loading, carrying and discharge of cargoes'.[15] The Institute published its own transactions, inviting contributions from members at sea, and was soon being described as a learned society. Branches were established lectures were given, and by 1899 the Institute had more than 1,000 members. Shipbuilders, too, had their own societies dotted around the coast, such as the 1824 Steam Engine Makers' Society in Liverpool, the 1857 Institution of Engineers and Shipbuilders in Scotland (IESIS), the Scottish Shipbuilders' Association established in 1860 which united with IESIS in 1864, and the North-East Coast Institution of Engineers and Shipbuilders from 1884. They held regular meetings, debated the technical topics of the day, invited members to attend from other similar bodies and published their proceedings. In 1859 IESIS began its first inter-library exchange of *Transactions*, the result of a letter from the Association of Architects, Engineers and Surveyors in South Australia, and it went on to publish nearly 1,700 papers on shipbuilding and engineering, an extensive proliferation of learned and practical documents. By 1968 the IESIS library was exchanging with nearly 100 others throughout the world. Today it flourishes in a new format, being one of several traditional organisations that have regenerated for the twenty-first century.

Senior LR staff often delivered technical papers to these societies. William John, for example, Principal Assistant to Benjamin Martell, wrote several papers for the INA, covering subjects such as *The Strength of Iron Ships, Transverse and Other Strains of Ships* and *The Cellular Construction of Merchant Ships*. John's contributions were described on his early death in 1891 as 'amongst the most important contributions which have ever been made to the technical literature of shipbuilding, and have contributed greatly to the proper diffusion of knowledge on these subjects throughout the profession'.[16] His work on the strength of ships, laying down the basis of comparing the stresses on different ships, was still the accepted basis of comparison in the 1960s. John left the Society in 1881, taking his expertise into the commercial sector to run the Barrow Shipbuilding and Engineering Company and helped to design and build several famous liners including *City of Rome* and *Normandie*.

The process of diffusion extended beyond the UK, often because of the country's dominant world role. British shipping, merchant and naval, was a frequent sight on the high seas and in distant ports, while more and more ships were built for owners outside the UK, and LR as the leading classification society made use of its growing network of overseas surveyors. The number of LR surveyors working overseas increased from five

in 1870 to 22 in 1873 and 66 in 1884, covering countries from France and the US to the Philippines and China. Openness over technical and scientific information was also practised in other countries. In the Netherlands Bruno Tiedeman published the results of his model tests, which led overseas navies and commercial shipbuilders to use the Amsterdam tank, and encouraged Dutch shipping companies to place more orders with Dutch shipyards from the 1880s. There were genuine attempts to establish international information exchange networks. When members of the INA travelled to Paris in 1895 and Hamburg in 1896, technical sessions were a feature of their meetings with their counterparts. In 1897, INA hosted the French and Germans, an event described as the International Congress of Naval Architects and Marine Engineers.

## William Fairbairn (1789–1874)

William Fairbairn was a Scottish shipbuilder and civil engineer who built vessels including the *Lord Dundas* and the HMS *Megaera*.

Fairbairn was born in Kelso, Scotland, and worked as an apprentice millwright in Newcastle, where he met George Stephenson. In 1816, after an argument with his employer in Manchester he opened his own iron foundry and was joined by James Lillie the following year. Under the name Fairbairn and Lillie Engine Makers, the partnership designed and built iron steamboats, greatly improved millwork and waterwheels, and steamboats, exporting to Scotland and some regions of Europe.

By 1830, Fairbairn and Lillie Engine Makers entered the shipbuilding industry by constructing the *Lord Dundas*, an iron-hulled steamboat. Fairbairn and Lillie expanded the business by manufacturing boilers for locomotives, as well as continuing their shipbuilding activities. The *Lord Dundas* proved so successful that over the next three years Fairbairn and Lillie built eight larger steamboats to be used in ferrying passengers across Scottish canals.

Fairbairn and Lillie's partnership ended after 15 years, due to latter's refusal to expand into the shipping industry, prompting a company name change to William Fairbairn & Sons. Despite this, Lillie continued to work for the company until 1839. Fairbairn decided to increase the production of shipbuilding within the company. One of his most ambition projects, the *Minerva*, an iron-hulled paddle steamer, was the first of its kind and operated on Lake Zurich in Switzerland. In 1835, to make his shipbuilding production more efficient, Fairbairn decided to move his shipbuilding business from Manchester to Millwall, London.

William Fairbairn & Sons produced over 80 ships at the Millwall yard. In 1848, Fairbairn retired from the shipbuilding division of William Fairbairn & Sons.

The company was also well known for its efforts within the locomotive industry from 1839. William Fairbairn & Sons began its development of locomotives by designing the 0-4-0 design for the Manchester and Bolton Railway. The company's locomotive division was eventually sold in 1864. In addition to the locomotive industry, William Fairbairn & Sons also manufactured boilers, which had been a vital part of the business. His expertise on boilers resulted in the UK Parliament requesting, 17 years later, that he research metal fatigue as well as giving evidence on accidents from machines in factories.

Fairbairn's versatility was exhibited in his research into the safety of machinery and structures. He frequently tested his own buildings and boilers for structural weakness, and aided other engineers' investigations.

Fairbairn was a member of several institutions, as well as a Fellow of the Royal Society and President of the Institution of Mechanical Engineers and was knighted in 1869. He died in 1874 from a severe bronchial cold.

By now, the occupations of engineer and naval architect had become respected professions. The record of one highly regarded marine engineer, A D Bryce Douglas, who died aged 50 in 1891, illustrates how far opportunities had expanded for talented, well-educated and experienced engineers. Bryce Douglas studied engineering at Glasgow University before becoming an apprentice with Randolph, Elder & Co. He then went to sea, becoming Superintending Engineer of the Pacific Steam Navigation Company in 1869, before leaving to set up his own practice as a consulting engineer. He then took over the engineering department of John Elder & Co. from Alexander Kirk before moving to run the works of the Barrow Shipbuilding Company.

While the benefits of the work of Rankine, Froude and others were most directly related to improved ship design and construction, their research was also instrumental in helping to improve safety at sea, as the disaster of HMS *Captain* had tragically illustrated. The new technologies in themselves had not improved safety. Between 1867 and 1882 more than 33,000 seamen and nearly 6,000 passengers lost their lives on British vessels alone (excluding fishing vessels), figures that seem extraordinary today. Four thousand lives were lost in 1881, a year blighted by particularly bad storms, making it the worst year on record to that time, and the average number of crew deaths at sea between 1877 and 1885 was 578. One contributory factor was the construction of ships with double bottoms for extra strength, following the example of the *Great Eastern*. No account was taken of the fact that this raised the height of the vessel's centre of gravity, and as a result, some of these slender, narrow ships were unstable, resulting in a number of casualties. The belated acceptance of Froude's work by commercial shipbuilders during the 1880s helped to conquer this problem.

The shifting of cargoes, as Francis Elgar, another graduate of the revived School of Naval Architecture, and the first Professor of Naval Architecture at Glasgow, pointed out in 1887, was also 'one of the chief causes of the foundering of steamers and iron sailing ships at sea'.[17] He recommended that the stability of every cargo vessel should be calculated prior to sailing, and clear instructions given to those responsible for loading them. This was all part of the debate on load lines that had been taking place since the 1830s. LR had played a leading role in the debate, and had made the first attempt at regulating the loading of ships in 1835, with the introduction of the Lloyd's Rule of three inches of freeboard per every foot depth of hold, which was extensively used until 1880. The story of load lines is one of a battle against vested interests, the hostility of the industry towards any attempt at regulation and the disregard paid to the advice of those advocating their compulsion in the interests of safety. As the arguments became ever fiercer, the Society continued to make the running, introducing rules governing load lines for specific ship types in the 1870s such as awning deck vessels. While this provoked the wrath of some steamship owners, many others were seeking the Society's advice on loading. The British Member of Parliament (MP) Samuel Plimsoll took up the cause, and yet another enquiry, the Royal Commission on Unseaworthy Ships, was set up in 1873. The Society's Chief Surveyor, Benjamin Martell, was passionate in advocating compulsion while demonstrating the scientific validity of load lines. Plimsoll frequently sought Martell's advice, and the famous Plimsoll Line was based on Martell's work. In 1886, the first official load line table in the UK was based almost entirely on the tables formulated and used by the Society. When load lines finally became compulsory through the UK Merchant Shipping Act, 1890, LR was one of the societies authorised to assign load lines. The same argument was taking place overseas, where other societies, Germanischer Lloyd (GL) and BV, were playing a similar role.

The load line debate encapsulated the pattern for intervening in the regulation of the merchant marine in the UK and elsewhere for much of the nineteenth century. The shipping industry was hostile to the imposition of regulation as a hindrance to the further development of an expanding sector of the international economy subject to increasing competition. Although steamship accidents were only a minority of casualties at sea early on, this changed as the steamship was more widely adopted, and in particular as ships increased in size; it was also a reflection of the changing proportion of the more vulnerable sailing fleet. With the reluctance of the state to intervene, the assessment of safety, rescue of casualties and improvements in safety measures were left to external bodies. In the UK these ranged from LR, the classification society, and the salvage associations, such as those founded by members of the shipping and insurance industries in Liverpool and Glasgow in the 1850s, to voluntary bodies such as the Corporation of Trinity House, responsible for aids to navigation around the coast of England and Wales, the Channel Islands and Gibraltar, and the Royal National Lifeboat Institution (RNLI), which developed a network of lifeboat stations.

Often, however, action to remedy deficiencies in systems or processes, whether by the state, industry or other organisations, was prompted only by tragedy. It had long been known that the use of iron in ships tended to throw the traditional magnetic compass off course. Yet it was only the loss of the large iron sailing ship *Tayleur*, wrecked off the Irish coast on her maiden voyage in 1854, one of the contributory factors being compass deviation, which prompted serious investigation into a remedy. This led to William Thomson's improved magnetic compass, developed in the 1870s, which remained the standard compass for merchant ships well into the second half of the twentieth century. Steadier at sea, it also overcame many of the deficiencies of its predecessors.

## Benjamin Martell and the Load Line

Benjamin Martell, LR's Principal Surveyor from 1872 to 1900, played a key role in the development of the load line regulations. From 1874 LR made load line a condition of classification, applying it specifically to newly built awning deck steamers – a type of vessel that often carried a light but bulky cargo – on which the line was marked by a diamond with a bar at each end and the letters LR. From December 1875, LR retroactively assigned load lines to all classed awning deck vessels. Benjamin Martell continued to gather data from surveyors at all ports, adding information on the vessel's strength and construction. Many leading shipowners also reported on their experience. When in 1870 the Associated Chambers of Commerce called for an Act determining a compulsory load line, LR Secretary George Seyfang responded to the concern that there were insufficient surveyors, stating 'we would gladly lend the Government all the help in our power to the whole extent of our staff; we would even increase our staff'. Martell read a paper to the INA in 1874 with his first proposals. In 1875 a conference was held between LR, the Board of Trade and the Liverpool Underwriters' Registry, at which they agreed fundamental principles. In January 1882, Benjamin Martell submitted a report to the General Committee of LR, based on years of research, including tables prepared from the accumulated experience of the LR staff and that of shipowners and builders. With tables prepared by Sir Digby Murray, they were the basis of the first Board of Trade load line tables of 1886, upon which the whole structure of the legislation was subsequently built. The final step of a legal requirement for a ship to carry a load line followed soon after, with the Merchant Shipping Act, 1890, which covered all the aspects required to make the issue of load lines work. The assigning authorities were LR, British Corporation and Bureau Veritas.

There were numerous examples of safety at sea becoming compromised by new technology because either corollary innovation did not take place or regulation failed to keep pace. For instance, stipulations were laid down for life-saving devices on board ship by the British Passengers' Acts of 1849, 1855 and 1863, and the carriage of lifeboats on cargo ships was regulated by the UK Merchant Shipping Act, 1854. Both these acts specified the minimum number and capacity of lifeboats to be carried on a sea-going ship based upon the vessel's tonnage, not on the number of people on board the vessel. In 1870, the Secretary to the Board of Trade, in answering a question in the House of Commons about the sinking of the passenger ship *Normandy* with the loss of 16 lives, said that 'in the opinion of the Board of Trade, it will not be possible to compel passenger steamers running between England and France to have boats sufficient for every numerous passenger they often carry. They would encumber the decks, and rather add to the danger than detract from it.' With the stipulations on life-saving appliances all but obsolete, it was not until the 1890s that the UK insisted that all overseas and home trade cargo ships should carry lifeboats sufficient for all on board. However, in the case of passenger and emigrant ships, because of opposition from the industry, the requirement was based not on numbers carried but the gross tonnage of the ship, the tragic consequences of which became fully evident only with the sinking of the *Titanic* in 1912 with the loss of over 1,500 lives. The theory that a large well-subdivided passenger ship was her own lifeboat had proved fatal.

There was growing concern that new technology was outpacing the ability of crews to cope. As early as 1865 Scott Russell had observed that 'In every improvement we introduce into machinery we must, in order to realise that improvement, put the machines into the hands of a better instructed and higher class of men, because, if a good engine falls into the hands of an uneducated, ignorant, careless or unqualified man, the greatest improvements possible only become tools of injury to the character of the engineers, and of loss to the owners'.[18]

When William Thomson introduced his magnetic compass, he expressed concern that naval officers were becoming overwhelmed by the array of new systems and a growing volume of information, and lacked the ability to manage them effectively. At the enquiry into the sinking of the Orient liner *Austral* in 1882, the principal cause again being adverse loading, some professional witnesses 'doubted the wisdom of placing in the hands of merchant-ship captains the results of calculations for stability expressed in the form of "metacentric diagrams" or "curves of stability", as to the average ship-captain of those days such curves and diagrams would have been unintelligible'.[19] Certification of British masters and officers was made law from 1851 and amended in the UK Merchant Shipping Act, 1854, to include home-trade vessels as well, and the Merchant Shipping Act Amendment Act, 1862, stipulated that engineers in the merchant service must be examined and hold a certificate from the Board of Trade. Although certain minimum standards for the qualification and treatment of seafarers had been prescribed by legislation, a lack of training and enforcement left a very unsatisfactory situation. The 1873 Royal Commission on Unseaworthy Ships attributed 65 per cent of lost British vessels from 1856 to 1862 to drunkenness, ignorance and incompetence, 30 per cent to weather and just 5 per cent to a lack of seaworthiness. The UK Merchant Shipping Act, 1894 consolidated previous legislation in an attempt to remedy the situation. Other traditional shipping nations also worked to solve similar problems, with Denmark and Norway enacting legislation in 1890 and Sweden in 1898, while others, such as the US, Germany and Spain, did so in the early twentieth century. France, on the other hand, had developed its own regulations in 1881 and 1893.

The growth of the international merchant marine, and the rising incidence of casualties, had first encouraged international collaboration during the 1840s, when Britain and France reached agreement on the standardisation of rules governing signalling at sea. An *International Code of Signals* had been introduced by the British in 1857, but this relied on flags and was of little use in poor weather, particularly fog.

In 1863 Britain invited a group of 19 other maritime nations to London, which led to their acceptance of Britain's *Rules for the Avoidance of Collisions at Sea*. By 1865, 34 countries had accepted the *Rules*, which were applied internationally by 1870. The exception was the US, which adopted its own rules in 1871, although it later agreed with several other countries to adopt the revised British anti-collision *Rules* in 1880. Even so, the *Rules* remained unclear and collisions continued to occur. Although Matthew Maury, Superintendent of the US Naval Observatory, had first proposed sea lanes in 1855, the idea was not adopted until 1900.

In all these moves, the lead had been taken by Britain, which was always reluctant to cede any part of its leading role in maritime affairs to any other nation, and in any case British governments had tended to follow an incremental approach to the regulation of the industry at home. But, as the maritime historian Sarah Palmer has written, 'the growing internationalisation of the maritime sector, with countries other than Britain developing a substantial oceanic presence, was forging a common sense of purpose among those who made their living from the sea.'[20] It was dissatisfaction with the British approach that led not only the US to propose a wide-ranging International Conference on Maritime Safety in Washington in 1889 but also the Norwegian representatives to put forward the idea of a permanent international maritime commission. A total of 28 nations sent delegations, ranging from the US, France, Germany, Russia and Japan to Sweden, Chile and Costa Rica. Britain attended the Washington Maritime Conference only reluctantly and on certain conditions. The programme was wide, ranging from rules for the prevention of collision and regulations governing seaworthiness to the necessary qualifications for officers and crew, lanes for steamers on busy routes and storm warnings. Most of the conference was devoted to discussion of the rules to prevent collision, and the use of signals and other means for indicating the direction of travel in fog, mist, snow, thick weather and at night. One of the British representatives was Rear-Admiral Philip Colomb, an acknowledged expert in the field of maritime safety and, unlike some of his peers, an enthusiast for the conference. He pointed out to an INA meeting in 1890 that the conference had dealt with the revision of rules that had emerged only on an ad hoc basis since 1839 and which had never been seriously reviewed since the steamer had become dominant. The British had, however, succeeded in downgrading the status of the conference and avoided any decision being taken either on a permanent international commission or on a uniform international load line. Although the British Government would continue to resist a consensus approach towards international maritime regulation, this was a trend increasingly hard to resist.

In the meantime, given the infancy of international regulation and the disinclination of states to intervene in industry, the classification society had assumed responsibility for promoting higher standards of ship design and construction. LR's example was followed by similar societies around the world: Bureau Veritas (BV) founded in Antwerp in 1829; the American Shipmasters' Association (later the American Bureau of Shipping, ABS) in 1862; Det Norske Veritas (DNV) in Norway in 1864; Germanischer Lloyd (GL) in Hamburg in 1867; and Teikoku Kaiji Kyokai (TKK), the Japanese classification society, in 1899, now Nippon Kaiji Kyokai (ClassNK).

As Sir Ronald Garrett, LR's Chairman, put it in 1957, 'it was not the Society's function to pioneer, but it was its function to help and encourage pioneering'.[21] Samuel Thearle, author of naval architecture textbooks and a distinguished LR Chief Ship Surveyor from 1909 to 1913, noted that 'it is the function of the Classification Society to collect results and interpret their teachings. It is its duty to criticise rather than to create, but its criticisms to be valuable must be based upon wide experience'.[22] To ensure that safety was paramount, the Society was cautious in assessing innovation based on knowledge accumulated from the practical operation of the new technologies.

Thus the evolution of many of LR's *Rules* ran in parallel with the process of technological innovation and adoption. For example, the engineering aspect of the new shipbuilding was only gradually absorbed within the classification process.

Since 1834 the Society had been content to rely on the report of a competent master engineer about the condition of a ship's engine, boiler and machinery, in which cases a notation of MC (Machinery Certificate) was assigned against the vessel's name in the *Register Book*. It was only in 1869 that engines and boilers were defined as part of a vessel's equipment, with classification conditional on their safety and efficiency; and it was 1874 by the time that the Society appointed its first engineer surveyor, William Parker, an appointment conceded on the grounds that steamships had become so numerous. Soon afterwards the classification of the hulls and machinery of all new vessels became interdependent for the first time and in 1879 a section was introduced to the *Rules* for the periodical inspection of all the machinery of every classed vessel and a new notation MS (in red), with date of survey, was introduced to the *Register Book*. *Rules* for boilers were introduced in the 1870s but without restriction on design or proportions, thus allowing future improvements. In 1888 *Rules* covering shafting were introduced, by which time the Society was already involved in inspecting and testing the material being supplied. So great was the demand for LR surveyors with engineering qualifications that ten years after the first appointment more than one-third of the Society's technical staff in the UK were engineer surveyors, and 26 similar appointments had been made abroad. By 1900, LR ship and engineer surveyors outnumbered ship surveyors.

As for the construction of ships, in 1855, 18 years after LR had classed its first iron ship, its *Rules for Iron Ships* appeared; this was 33 years after the *Aaron Manby* had crossed the English Channel and ten years after the *Great Britain* had sailed into New York. Even then, the Society refused to specify the adoption of any particular form of construction on the grounds that iron shipbuilding was still evolving, as indeed it was. Instead, the Society was willing to accept any alternative designs as long as the strength of the ship was unimpaired, denoting that in relation to the *Rules* such vessels were built 'equivalent thereto'. This flexible approach won the support of Scott Russell, and enabled the classification of a series of innovative vessels, from those built of iron and steel to the early purpose-built oil tankers. The *Rules* were also regularly reviewed, to eliminate weaknesses. For instance, the requirement to relate the thickness of scantlings to tonnage in the 1855 *Rules for the Building of Sea-Going Iron Ships* had resulted in very heavy hulls. In 1862 the Underwriters' Registry for Iron Vessels was set up in Liverpool due to dissatisfaction with the existing rules for iron ships. The LR *Rules* were amended in 1870 so that the scantlings were based on the relationship of the breadth of a vessel to its length and in 1885, after further changes to the *Rules* for iron-hulled vessels, the Liverpool Underwriters' Registry was amalgamated with LR.

The Society embraced innovation, contrary to the criticism it received in some quarters. Engineering innovations, for example, were given unconditional approval following a thorough investigation, provided safety was assured, while other innovations were given conditional approval subject to survey; only those ideas that were discovered to be totally unsuitable were disallowed.

Classification by LR became internationally regarded, and the Society was generally respected for its objectivity as it had no shareholders, even though it was funded through survey fees by the very people for whom it was carrying out surveys. Bernard Waymouth, the Society's Secretary, speaking in 1873, underlined the assiduity of surveyors in inspecting the progress of a ship under construction: 'The surveyor is supposed to watch closely the vessel during her construction, so as to slip nothing.' As well as assessing the quality of the materials and the way in which they should be used for shipbuilding, surveyors also inspected the quality of workmanship and advised on how best to minimise deterioration and decay. Waymouth was adamant that 'any vessel that would not stand a survey by Lloyd's [Register] ought not to be allowed to go to sea' while Benjamin Martell, the highly regarded Chief Surveyor, had no doubt that the classification process had improved construction standards worldwide.[23]

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1850-1900

# 7 The impact of shipping technology on the nineteenth-century world

The gradual evolution of the steamship had a revolutionary impact on the world. Its progress summed up so many of the major characteristics of the century. The heartland of its development was the most dominant nation on earth, whose extensive global connections helped to spread the steamship to the four corners of the world. It played a key role in accelerating globalisation, not just in trade but also in communications and culture.
The indispensable link between supply and demand, creating a fall in prices, stimulated developing economies and helped to feed expanding industrial populations. Industrialisation was essential in turning the steamer from a novelty into a mass-produced, everyday form of ocean transport. The skills of the engineer, combined with the development of modern science, finally achieved a synthesis of theory and practice. By 1900, this invention was no longer the preserve of any one nation but had become the key form of international transport.

As it had prior to 1760, the ship continued to act as an agent of globalisation; the difference during the nineteenth century was how shipping technology helped to accelerate this process in an age of change. O'Rourke and Williamson neatly summed this up: 'By 1914, there was hardly a village or a town anywhere on the globe whose prices were not influenced by distant foreign markets, whose infrastructure was not financed by foreign capital, whose engineering, manufacturing and even business skills were not imported from abroad, or whose labour markets were not influenced by the absence of those who had emigrated or by the presence of strangers who had immigrated.'[1] The same is true 100 years on.

The metal screw steamship that represented the bulk of the world's steam tonnage by 1900 was a remarkable development. The combination of steam power and metal hulls created waterborne transportation more efficient, more predictable, more capacious and more flexible than ever before. The basic template proved hugely adaptable. The general cargo steamer was a blend of the two main elements of an international maritime trading network, the cargo liner and the cargo tramp. It also metamorphosed into a wide variety of other carriers which became vital in world trade, from the bulk carriers and oil tankers to the refrigerated ships and long-distance passenger liners.

The World Trade Organization noted how international trade increased rapidly after 1820, underpinned by falling transport and communications costs. Economic historian Nils-Gustav Lundgren estimated that between 1870 and 1900, transatlantic transport costs fell by 60 per cent, and that between 1800 and 1910, inland transport costs fell by over 90 per cent. Economist Angus Maddison reported that over the same three decades, world exports expanded by an average of 3.4 per cent annually, substantially above the 2.1 per cent annual increase in world Gross Domestic Product (GDP), stating: 'As a result, the share of trade in output (or openness) rose steadily, reaching a high point in 1913, just before the First World War, which was not surpassed until the 1960s.'

Gradual technological development transformed the metal screw steamship into the most efficient form of seaborne transport the world had ever known. Its diffusion across the world was assisted by the dominance of the British mercantile marine. Britain dominated the world economy in the nineteenth century to an extent that no other nation in any other era has ever rivalled. By 1850 Britain was turning out more than 40 per cent of the world's entire output of traded manufactured goods, while British ports were handling around a quarter of world trade. Benefiting from the massive productivity gains of being the first industrial nation, Britain consumed huge quantities of raw materials, turning them into iron and steel, machinery, railway materials and other manufactured goods, and exported these all over the world. There was an enormous market for British goods as other nations began the process of catching up. The British economy became dominated by a handful of major industries – coal, textiles, shipbuilding and engineering, as the country became dependent, according to Peter Mathias, 'on its ability to sell cheap cloth, cheap iron, machinery and coal, and to provide the ships to carry the cargoes, to the rest of the world'.[2] As production in many of these industries increased, so Britain could no longer meet the demand for some materials from its own resources, and an increasing proportion had to be imported. By 1913 it was importing nearly 90 per cent of all raw material supplies, including 80 per cent of all the wool it needed and almost all the ore. Britain was also importing more than half of all the country's food, including 40 per cent of all its meat and 55 per cent of all its grain.

The steamship met the challenges posed by Britain's industrialisation. Ocean transport costs tumbled as the efficiency of the steamship increased within an increasingly sophisticated international trading network. With the wider adoption of the steamship after 1850, freight rates by 1900 were as much as 30 per cent lower than a century earlier. The steamer was supported on the land-based side of the supply chain by the improved infrastructure of major ports and harbours and by the equally revolutionary steam locomotive.

Swansea had been a major centre of copper smelting, but by the 1880s the improved supply chain made it possible to ship Welsh coke to smelting plants in mining areas of the US, where it was used to turn ore into pure copper, which was then shipped back to Europe. As a round-trip of several thousand miles, this was a precursor of today's extended global supply lines, made possible thanks only to the steamship, the steam locomotive and the developments in port facilities.

The impact of the steamship in creating cheaper transport helped to create global commodity markets, such as the international grain market, and to bring about a convergence of commodity prices. By 1890, the steamship had narrowed the gap between wheat prices in the UK and the US. Without the steamship, it would have been impossible to realise the potential of refrigeration in helping to feed the population of industrial nations while stimulating the economy of pastoral nations. Meat, butter and cheese, once relative luxuries for urban populations, became part of an everyday diet for most people, thanks to the fall in prices arising from the greater volume of goods carried by the steamship. By 1914, refrigeration had enabled the UK to import every year the equivalent of 20 pounds of beef and mutton per head of population. The same flexibility that enabled the steamer to become a refrigerated cargo carrier also transformed it into a specialist carrier of bulk goods, from timber and coal to copper and iron ore and petroleum, ensuring prices fell as a result.

Similarly, the general cargo steamer helped to stimulate the economies of West Africa, Egypt and India, in exporting palm oil, cocoa and cotton. It was even argued that the steamer itself could encourage trade. The example given by Kirkaldy and Evans in 1914 was trade between Europe and West Australia. They suggested that this had been minimal prior to the 1880s, served only by two small sailing ships operated by two London shipping firms due to the time it took to complete the crossing under sail. In 1884, the service was extended to Singapore thanks to the purchase of a small steamer, stimulating more trade. This encouraged the acquisition of a second steamer, and within a few years, the volume of trade had led to the involvement of several shipping companies.

The steamship was also instrumental in revolutionising communications. Faster steamers delivered mail more rapidly. The unsubsidised mail service operated by Orient Line on the route to Australia and New Zealand achieved better results than its subsidised competitors, shaving ten days or more from delivery times. In 1880 the liner *Orient* brought letters from Adelaide to London in just 31 days. Also, the steamship helped to create the worldwide network of underwater cables. All this made it easier and cheaper to communicate over long distances, with the rising tide of messages producing 'an unparalleled diffusion of common ideas'.[3] By 1914 there was a global cable network, supplemented by an extensive landline network. The impact must have been as great as the appearance of mobile phones a century later. It revolutionised the way business was done, as Lars Scholl describes: 'The cotton, coffee, sugar and tobacco trades immediately published lists of prices current and other market information via telegraphic transmission, thus influencing international trade and shipping to an unprecedented degree.'[4] LR's work also benefited from the improvements in communications, as it allowed an almost immediate response to urgent queries regarding ship safety, a development that continued to allow the Society to ensure that it was in touch with the technologies around the world.

An intangible impact of the passenger ship was the role it played in disseminating cultural influences, helped by the dramatic reduction in the length of steamship voyages. The westward voyage from Europe to Canada shrank from as long as a month in the 1820s to just seven days by 1900; the Cape run, which took three months in the early nineteenth century, lasted just 14 days by 1900; while the voyage to Australia was cut from the 100 days needed by the sailing clippers to just over 30 days by the 1890s.

## David Napier (1790–1869)

David Napier was a Scottish marine engineer, and one of Britain's greatest mariners to explore deep-sea steam navigation.

As a child, Napier was avidly interested in shipping. His grandfather, Robert, had married Jean Denny of Dumbarton, a marriage of Scotland's two most influential engineering families. As a child, David's father, John (1752–1813), took him to see the *Charlotte Dundas* built by William Symington.

When David was 12, his father moved his engineering company and iron works to Camlachie, Glasgow, where David worked as a shipping engineer. Eight years later, his father's health having declined, David took control of the family business; by 22, he had built a boiler for Henry Bell's *Comet* – a 28-ton paddle steamer that was Europe's first commercially successful steamboat. A year later, his father died.

At 31, David moved to Lancefield Quay on the Clyde, a hotbed of ship innovation, where he honed his shipbuilding skills; six years later, he had built the *Aglaia*, a 49-ton iron paddle-steamer. He was criticised for the explosions involving his boilers, especially on the *Earl Grey* in 1835 at Greenock, which killed six people. Due to the high volume of similar incidents during the 1830s, the accusations were retracted.

In 1836, Napier bought land at Millwall on the Thames, next to the yard of William Fairbairn, another influential steam engineer. At Millwall, he experimented with steam displacement, engines and propulsion. His factory on the River Clyde failed to keep up with competition, and closed in 1852. Down on the River Thames, Fairbairn amalgamated his yard with Napier's where John Scott Russell and Isambard Kingdom Brunel were busy with the *Great Eastern*.

David died aged 79 at Kensington, London in 1869.

## Robert Napier (1791–1876)

Robert Napier, cousin of David, became known as 'the father of Clyde shipbuilding'.

Robert was born on 21 June 1791 to James and Jean Napier at Dumbarton. He became interested in the family business of forge welding and engineering, and worked as an apprentice for five years. He left to join Robert Stevenson, an engineer renowned for his work on Bell Rock Lighthouse.

At 25, Robert formed his own business, Robert Napier & Sons, in Glasgow. Within a few months, he was made a Burgess of Glasgow, then joined a committee governing Glasgow's engineering trades, the Incorporation of Hammermen, a moment he described as the most important of his life. In 1818, he married his cousin, Isabella, David's sister.

Robert had received numerous engineering commissions; it was his ability to manufacture pipes for steam engines that proved to be the most useful. This resulted in a contract for him to build a steam engine for the *Leven*, the first he had ever built. It proved so successful that it was fitted to another vessel, the *Queen of Beauty*.

The skill of Robert's employees demonstrated his eye for engineering talent. He took on many influential engineers, such as James Thomson, who went on to form John Brown & Company with his brother George (who had also worked for Napier), and John Elder who was later to form the Fairfield Shipbuilding and Engineering Company.

Between the late 1820s and early 1830s, Robert built the Vulcan foundry in Glasgow. He was also consulted about the possibility of a steamship service running regularly from Liverpool to New York. In 1835, he was commissioned by the East India Company to produce engines for their ocean-going paddle steamer the *Berenice*.

Following his successes, the Admiralty commissioned Robert to build two 280 hp nautical engines. During this time, Robert met Samuel Cunard, who was considering a transatlantic liner and mail service. The British Government, approving of Cunard's proposal, asked him to find an engineer who could fit such vessels. The engineer was Napier, whose engines were used in the first-class paddle steamers *Stromboli* and *Vesuvius*. Despite the difficulties of the commission, Robert persisted, stating, 'I cannot and will not admit of anything into these engines but what is sound and good'. Eventually, he provided engines for four ships, one of which, the *Caledonia*, was built in the Dumbarton shipyard.

Robert's efficiency led to more dealings with Cunard, including the formation of the British and North American Royal Mail Steam Packet Company, in which Robert raised over 80 per cent of the equity. He and his fellow shipbuilders were under pressure to construct the ships; delays would result in financial penalties and damage to their reputations. Fortunately, the ships were delivered on time and the company was a success. Robert's engineering abilities and administrative skills were praised; he had successfully funded, structured and maintained the company. That company, now known as the Cunard Line, still operates, 175 years later.

In 1841, Robert Napier & Sons expanded to accommodate iron shipbuilding with the Parkhead Forge Steelworks. The growth in premises allowed the construction of the *Vanguard, Jackal, Lizard* and *Bloodhound* for the Royal Navy.

In 1875, Robert's wife Isabella died, aged 57. Left devastated by her loss he became a recluse and refused to continue with his usual affairs; a year later he died in West Shandon, aged 85.

Among the steamship lines opening up passenger routes to Asia was the Bibby Line, offering regular scheduled voyages to Ceylon and Burma from the 1890s, improving passenger capacity and accommodation standards with each successive new ship ordered. These were all regular and reliable services. The steamship made it so much easier and speedier for people to travel great distances, transforming their lives, not only the migrants making a new start in a new country, but women now able to travel as nurses, teachers and doctors, and pupils from overseas enabled to study at leading European institutions. In the words of maritime historian Richard Woodman, 'The advantages of the steamship were well understood by the general public, many of whom were making voyages inconceivable to their parents'.[5] With them went ideas and knowledge; there were favourable shipping rates for the carriage of historic artefacts, school textbooks, library books and botanic specimens.

All this highlighted the interconnectedness of the process of innovation, as others responded to the potential of the steamship, from the colliery owners of Tyneside to the sheep farmers of Australia and New Zealand. The steamship became a major link in a global chain of innovation as well as a central part of an expanding international economy. As the medium that connected supply and demand, source and markets, the steamship benefited not only countries like Britain and the US, but also helped to create a sustained trade boom in Asia from the 1870s.

For O'Rourke and Williamson, 'Sharply declining transport costs brought distant national markets much closer together than at any other time before. International and inter-continental trade flourished, regions and countries increased commodity specialisation, and formerly self-sufficient peasants in Russia, farmers in Kansas and artisans in Japan were brought into intimate contact with the world economy.'[6]

Industrialisation and science were instrumental in the development of the metal screw steamer. The spread of the steamship with its many advantages was a function of the expansion of world trade, which rose tenfold between 1850 and 1913, stimulated by the industrialisation of Britain, America and others. Without the engineering firms, iron foundries and steelworks, the mass production, volume of materials and technical skills needed to turn the steamship from a novelty into the indispensable workhorse of the open seas would have been impossible. But the metal screw steamer not only epitomised the impact of industrialisation; it also represented the cumulative contribution of countless innovators, both engineers and scientists. It was engineers such as Fulton, Napier and Pettit Smith whose pioneering empirical work laid the foundations upon which others would build.

From the engineer-scientists such as Brunel and Scott Russell to the theoretical scientists like Rankine and Froude, the transformation of ship design and construction combined with the adoption of new materials and methods of propulsion engendered a more scientific and analytical approach, and the gap between theory and practice was finally bridged.

This was not an overnight process. Although the pace of development was gradual – the time lag between an invention to its wider adoption could stretch over decades – the result was revolutionary. The classification society played an important role as an intermediary in this process, assessing the impact of new technologies, the quality of materials, and the soundness of construction methods. The *Rules*, covering construction, materials, machinery and engineering, were important for two main reasons. They were flexible enough to encourage continued innovation, while the guidance they laid down for shipbuilders and ship designers helped to convince conservative shipowners to take up ever more efficient versions of the metal steamship.

The most enlightened and inspired shipowners had a crucial role to play in persuading their peers to follow them, not only in the debates held within professional bodies up and down the country, but also by example. Many shipowners were more than happy to copy the lead of men such as Charles Palmer, Samuel Cunard, Alfred Holt, Robert and Ludvig Nobel, and Marcus Samuel. Other nations followed the British example, establishing their own professional societies. In the US, a group of officers from the US Navy's Engineer Corps set up the American Society of Naval Engineers in 1888, and the Society of Naval Architects and Marine Engineers (SNAME) was founded in 1893; in Japan, the Zosen Kyokai was founded in 1897, with the Society of Naval Architects of Japan the following year; and the German Society for Marine Technology (Schiffbautechnisches Gesellschaft) was formed in Berlin in 1899.

Behind the success of these groups of determined individuals was the constant search for economies of scale, leading to larger and larger ships powered by more and more efficient engines and machinery. Ship size and fuel efficiency would continue to be the main elements of the search for further economies in an increasingly competitive market. It was this commercial imperative that within the span of a century had seen the steamer transfer from the rivers, canals, lochs and lakes of Scotland and North America to every ocean on the planet.

In its global reach, the steamship transcended national identity, despite the pride of shipping companies in their house flags and colours and the rivalry between competing national lines. This internationalism could be seen in the beginnings of cross-border collaboration between the professions, and between nation states as they pursued the international regulation of shipping. It was the Norwegians, operating the third-largest fleet in the world by the 1880s, who argued that it mattered little whether goods were carried in the ships of any one nation so long as the contract was fulfilled to price and on time. The steamship had become the acme of international haulage.[8]

**End Notes**

[1] Kevin O'Rourke & Jeffrey G Williamson, *Globalisation and History, The Evolution of a Nineteenth-Century Atlantic Economy* (Massachusetts, 1999) p2

[2] World Trade Organization, *World Trade Report 2013: Factors affecting the future of world trade* (Geneva, 2013) p47

[3] Peter Mathias, *The First Industrial Nation, The Economic History of Great Britain 1700–1914* (Abingdon, 2001) p231

[4] Christopher A Bayly, *The Birth of the Modern World, 1780–1914* (Oxford, 2004) p20

[5] Lars U Scholl, 'The Global Communications Industry and its Impact on International Shipping before 1914', in David J Starkey and Gelina Harlaftis, *Global Markets: The Internationalisation of the Sea Transport Industries since 1850,* Research in Maritime History No 14 (St John's, Newfoundland, 1998) p201

[6] Richard Woodman, *The History of the Ship* (London, 1997) p170

[7] O'Rourke & Williamson, *Globalisation and History* (Massachusetts, 1999) p55

[8] Sarah Palmer, 'Leaders and Followers: The Development of International Maritime Policy in the Nineteenth Century' *International Journal of Maritime History*, 17 (December, 2005) pp299–309

# 1900-1945

# 8 The motorship and the oil tanker

By 1900 continuous improvement had turned the cargo steamer into an efficient means of seaborne transport. The steam turbine proved unattractive for many cargo operators but the advent of the marine diesel engine created a worthy competitor for the steamship. The motorship, and in particular the motor tanker, was enthusiastically taken up by the mercantile marine of nations lacking the coal resources that powered most of the UK's merchant fleet. By 1939, Norwegian shipowners were the world's leading operators of ever larger motor tankers. Competition from the motorship helped to drive the further refinement of the steam engine, while a minority of steamers took up 'dual fuel' boilers, with the ability to switch from coal to oil whenever economic. It was economies of scale, and the search for fuel efficiency, that lay behind many of these improvements as operators strove to cut costs during a tough worldwide depression in shipping. On the other hand, the impetus to continue developing a recent shipbuilding technique, welding, came from the need to produce more shipping more quickly in wartime. Among other advances, the wireless became an essential part of safety at sea, as international regulation became more effective. Engineers and naval architects also began to work more closely together, embracing the more technical approach developed in previous years, while their professional societies and the classification societies maintained their role in furthering knowledge and research. International trade was still growing significantly at the beginning of this period and by 1913 exports as a percentage of the world GDP had reached nearly 8 per cent, a figure that would be unsurpassed until the 1960s. The First World War sent international trade into reverse and ushered in an era of tariffs and duties as developed nations strove to protect their shattered post-war economies. By the 1930s, the average tariff rate worldwide had risen to 25 per cent. Both shipbuilders and shipowners concentrated on economy of operation as freights fell, when between 1929 and 1934 the value of international trade collapsed by two-thirds. The outlook was still gloomy when the world went to war once again in 1939.

Thanks to the accumulated advances of the previous half-century, the efficiency of the ordinary, everyday, run-of-the-mill steamship in 1900 bore no comparison with her extravagant under-powered predecessors. Built of steel, stronger, cheaper and more reliable than iron, giving bigger, lighter hulls, and powered by cheap and reliable if modestly fuel-efficient triple-expansion engines, she used water for ballast, electricity for internal illumination and later, on auxiliary power.

In the latest edition of his work on naval architecture published that year, William White, one of the leading naval architects of the day, highlighted the most important advances of recent years. First, increased steam pressure, leading to more power and lower fuel consumption; second, the increased rate of revolution and piston speeds, enabling economy in the weight of machinery relative to the power developed; and third, new types of marine boiler to generate higher pressures, notably the water-tube boiler. As an example, he pointed to the greater economy achieved by a passenger steamer travelling at 16 knots en route to Australia: in 1881, powered by compound engines, it consumed an average of 125 tons a day; in 1900, with triple-expansion engines, this was reduced to 100 tons a day. Similar improvements applied to the general cargo steamer, which became an even more efficient carrier of long-distance cargoes. Greater fuel efficiency meant less coal carried, thus increasing valuable freight-earning cargo space. White underlined just how cheaply such ships could carry goods, calculating that over 3,000 miles she carried 3,000 tons of cargo for every pound spent on coal.

The apogee of the reciprocating steam engine was the German passenger liner *Kaiser Wilhelm II* of 1903, with her two 20,000 ihp tandem-coupled six-crank quadruple-expansion engines, fired by 12 double- and seven single-ended boilers in four engine rooms. While the reciprocating steam engine remained the standard form of propulsion for thousands of ships around the world until the 1950s, it became overshadowed by the more powerful steam turbine.

Quickly taken up by the Royal Navy, its commercial adoption took a little longer, stimulated by the private syndicate run jointly by Charles Parsons, William Denny and Brothers and the operator of a fleet of Clyde paddle steamers. In 1901–1902 the syndicate launched the turbine-powered passenger steamer *King Edward* and her sister ship *Queen Alexandra* on the River Clyde in a bid to attract interest from merchant shipowners. Entering service in 1901, the *King Edward* was the world's first commercial steam-turbine-powered vessel. The speculative venture showed a fuel saving of 15 per cent over a similar vessel powered by a triple-expansion engine. This innovation also attracted the attention of the leading British shipowner Sir Christopher Furness. Eager to encourage the development of the turbine as an alternative to the reciprocating engine, his yacht *Emerald* was fitted with a turbine in 1903. She was the first turbine vessel to cross the Atlantic and the first to be classed by LR.

Although the fuel economy of the early turbines had initially been poor, Parsons demonstrated that economy improved with size. He had also conducted further research into minimising the problem of cavitation, which helped to increase the turbine's efficiency through better propulsion. Moreover, initial costs were less than those of the reciprocating engine and the turbine took up less space. But it was the turbine's advantages in terms of speed that first attracted merchant shipowners, in particular those operating passenger services. Remarkably, within three years the steam turbine was being fitted to major passenger liners, the owners attracted by the extra power as well as the fuel efficiency. In 1905, Allan Line's 10,750 grt *Victorian* and *Virginian*, fitted with three turbines, each directly driving one propeller, became the first commercial turbine steamers to sail the North Atlantic. Two years later they were joined by the world's largest and fastest ships, the prestigious Cunard transatlantic liners *Lusitania* and *Mauretania*. LR played a key role in this project. The Society's Chief Engineer Surveyor, James Milton, became an acknowledged expert on the steam turbine, and was part of the committee appointed by Cunard which recommended the decision to install turbines for these two liners.

The ships were built under LR's special survey and at the special request of Cunard, in addition to the usual classification work, the Society's staff also acted as superintendents on behalf of the owners throughout construction. As Samuel Thearle, the Chief Ship Surveyor, noted, this highlighted the Society's flexible approach to the *Rules*, as well as its technical expertise, in order to accommodate advancing technology. LR, he said, 'had to go back upon first principles, and, by the aid of elaborate mathematical investigation, test the sufficiency or otherwise of the scantlings and arrangements first suggested for the ship'.[1] Both ships also made extensive use of higher tensile steel.

The early direct drive turbines were powerful, but speed was not a priority for most cargo ships. In this regard, the early turbine also had little advantage over the triple-expansion engine in terms of fuel economy and there were difficulties in applying a turbine to the large single screw favoured by most cargo vessels. For more general use, Parsons went on to develop the geared turbine, which proved almost as economical as the triple-expansion engine; it was only in the 1920s that larger British merchant ships began to adopt the turbine in tandem with oil-burning and water-tube boilers.

Nevertheless, the triple-expansion steam engine remained the most common form of prime mover for smaller ships during this period. The pattern for that engine, and for other existing technologies, was one of continuous improvement, spurred by competition for scarce shipbuilding orders, as engineers sought further fuel economy, a pattern repeated at the end of the century. Superheating was developed in the late nineteenth century to raise the temperature of steam above natural boiling point or vaporisation temperature, thus imparting additional energy to it. Waste heat was also becoming more widely re-used to pre-heat and reduce condensation, thus improving efficiency. There was also increasing research into cavitation. The conventional fire-tube Scotch boiler benefited from the improving quality of steel, making it both stronger and lighter, capable of withstanding ever higher pressures while contributing towards lower fuel consumption through a reduction in weight. There were limits to the output of the Scotch boiler but there was a continuing reluctance on the part of British merchant shipowners before 1939 to adopt the water-tube boiler, despite its increased efficiency and its use by the Royal Navy. The Scotch boiler was also widely used by shipbuilders in the Netherlands and further afield.

Coal-rich nations with established merchant navies such as Britain, France and Germany had little need to seek a radical alternative to a method of propulsion tried, tested and still undergoing improvement. The earliest attempts to utilise oil as a substitute to fuel boilers had taken place around 1875. While oil was expensive, there were savings to be made from reducing the number of firemen and trimmers, and from replacing coal bunkers with revenue-generating cargo space. The obstacle lay in the limited supplies of oil at that time – 'Vessels proceeding on long voyages could not at present replenish their bunkers'[2] – while for the British they lay outside their territorial control.

Nevertheless, there was innovation and it came from merchant fleets, notably Scandinavian, lacking their own domestic fuel resources. They took an emerging technology, the marine diesel engine, and combined it with the first really successful method of longitudinal construction, to create a fleet of specialist oil tankers. Their construction was financed on the strength of charter parties from oil companies, their oil supplies secured by trading between oil ports. Rudolf Diesel patented his oil engine in 1892, and by 1897 several marine engine builders, including Burmeister & Wain, MAN and Sulzer, had taken an interest, with others following after the expiry of Diesel's patents in the early 1900s. The first marine 'diesel' engine was finally built in 1902–1903, just ten years after Diesel's invention, by Bocket and Dyckoff, and was fitted to a French canal boat. One of the drawbacks of the engine's commercial application for deep sea ships, however, was its inability to reverse, initially solved by the use of ancillary electric motors, and then overcome by the reversing engines made by Burmeister & Wain in 1905 and Sulzer in 1906.

The 'diesel' engine, with 32 per cent thermal efficiency, was a significant improvement in terms of efficiency over the steam engine, reciprocating or turbine. In the motorship, one ton of oil was worth two to three tons in the oil-fired steamship, while the absence of boilers and smaller bunker volume created more space for cargo and required fewer crew. In 1911 one writer, comparing the oil engine with the steam turbine, concluded that 'the higher overall efficiency of coal-gas or oil engines or turbines will certainly prove alluring, and if the world's production of oil should increase, and the price be reduced in the immediate future, the engineer will be stimulated to overcome the difficulties'.[3] LR was closely involved with these developments.
The Society classed several of the larger early motorships, including the *Selandia* and *Fionia* built in Copenhagen by Burmeister & Wain.
The British Corporation classed another early motorship, *Jutlandia* built by Barclay, Curle & Co. Ltd, Glasgow. This experience, and the expertise of LR's Chief Engineer Surveyor James Milton, resulted in the first *Rules for Diesel Engines* in 1914. Given the limited experience of such engines at sea, LR recognised that the *Rules* 'must be considered as subject to such modifications as might be shown to be necessary in the course of longer and more extended experience'.

The first ocean-going ship equipped with a diesel engine was constructed by Nederlandsche Scheepsbouw Maatschappij, Amsterdam, in 1910. The LR-classed *Vulcanus* was an oil tanker operating for registered owners Nederlandsche-Indische Tankstoomboot Maatschippij, with manager Anglo-Saxon Petroleum Co. Ltd, a subsidiary of Shell. She reportedly consumed two tons of oil for every 11 tons of coal in a steamship, and required 16 rather than 30 crew members, largely due to not needing stokers. The commercial benefits for the tanker company were obvious. This was already appreciated by Norwegian shipowners, and the first large motorship ordered from a Norwegian yard (A/S Akers Mekaniske Værksted, Oslo) was the 2,388 grt *Brazil*, completed in 1914.

By then, oil tankers carried virtually all the world's oil on the high seas. They had been steadily growing in size but now they were stretching the limits of current design and construction methods. Conventional transverse framing limited ships to around 12,000 tons deadweight (dwt), beyond which there was a tendency for hulls to buckle. Brunel, Scott Russell and others were among those who for years had sought a satisfactory method of longitudinal construction, but the breakthrough came only with the Isherwood System patented in 1906 by Joseph Isherwood, who was still working for LR as a surveyor at the time. This was the first successful method of longitudinal framing, giving a stronger hull and using less steel, thus lowering the cost of construction and saving fuel.

It was an attractive option for the owners of tankers, constantly seeking cost savings, which had become more difficult as ships became larger. The first ship to adopt the System, the 6,400 tons deadweight *Paul Paix*, was built in 1908 by R Craggs & Sons of Middlesbrough, a shipyard that Isherwood joined on leaving LR. She was classed by LR jointly with the British Corporation, and 275 tons of steel was saved in her construction over conventional methods. In the following year LR published its *Rules for the Construction of Vessels Intended for the Carriage of Petroleum in Bulk*. The Isherwood System became the standard method of construction for oil tankers. By 1912, 240 vessels in excess of a million tons were contracted for construction using the System, spread across British, American, German, Dutch, Canadian, Belgian and French shipbuilders. Most steam oil tankers on order in that year were adopting the Isherwood System, a few reaching 15,000 dwt, a size not generally exceeded until after 1945. By the time of Isherwood's death in 1937, more than 2,500 cargo ships and oil tankers had incorporated his special design.

Technically, tankers larger than 15,000 dwt would have been possible. However, the size of tanker ideal for the average length of tanker voyages was 12,000 dwt, especially since shorter voyages usually meant longer stays in ports that were limited in the size of vessel they could handle. Furthermore, the oil trade itself was becoming specialised, with a growing volume of refined petroleum divided into several different products.

The spread of the motorship was delayed by the First World War, but with the collapse of the short-lived post-war shipping boom the motorship became attractive for owners seeking to economise. The words of one contemporary British shipowner, Sir Archibald Ross, would have rung true nearly a century later, as he observed that 'the outstanding feature of the engineer's many problems today is the imperative necessity of extracting the maximum from the minimum amount of fuel'.[5] For one naval writer, Archibald Hurd, there was no competition between the steamship and the motorship, writing that 'the motorship in most conditions of sea transport is, first and last, the most economical cargo-carrier viewed from every standpoint'.[6] One pound of oil carried a ton of goods 75 miles by sea, compared with just 25 miles per pound of coal. By 1939 motor engines had become the propulsion of choice for half the world's tonnage. By the mid-1920s, author Alfred Cecil Hardy noted that there were already more oil bunkering stations around the world than there had ever been coaling stations. By giving motorships security of supply and even a choice in picking the cheapest ports to refuel, this development fulfilled the condition that the feasibility of any system of mechanical propulsion depended on the price and availability of fuel. This is just as relevant today as shipowners seek to adopt liquefied natural gas – though there were at the time other important factors to consider, such as the shortage of motor engines and initially lower reliability than steam.

Development of the marine diesel also stimulated improvements in the marine steam engine. Sir Archibald Ross noted that 'the advent of the diesel engine has given a stimulus to engineers engaged in the design and manufacture of steam machinery, and probably the efficiency of an up-to-date installation of steam engines and boilers would not have been as good today had it not been for the serious competition offered by the diesel engine'.[7] Norwegian historian Kaare Petersen noted that steamships launched in the late 1930s consumed half as much coal as similar-sized vessels launched in 1912; other historians have noted that this was closer to about two-thirds.

A compromise between these was the vessel that had the option of burning either coal or oil, switching from one to the other depending on fluctuations in fuel prices. Figures from LR's *Reports of the Society's Operations* revealed that by 1929 more than 19 million gross tons of steam vessels classed by LR had been originally fitted to burn oil or had been converted for that purpose. LR observed that it should not be assumed that all steamers were using oil, since 'a number of these installations can readily be replaced by coal-burning fittings when the occasion demands the use of coal in preference to oil'.[8] There was an advantage in this technology for the tramp steamer, with its flexible itinerary, seeking trade from any port possible, some of which in the inter-war years would not have been able to supply bunker oil. It also meant that tramp ships could take advantage of the cheapest price when both fuels were available.

As some shipowners conceded, this development also sprang from the conservatism of many British owners and the failure of builders to persuade them to commit themselves completely to a relatively new technology. Ignorance too played a part, as did the unhappy experience of some owners with motorships that had failed in the hands of inexperienced crew.

The relationship between owner and builder had been illuminated by Leonard Peskett, Cunard's Chief Naval Architect, and the designer of the *Lusitania* and *Mauretania*, when he spoke to the INA in 1914. He observed that owners were driven by competition to adopt innovations but they also emphasised the primacy of commercial considerations:

> *'The evolution of the design must, in fact, be developed from the owner's experience and data, if the finished ship is to prove a successful commercial asset. A builder may produce a vessel possessing every virtue as regards perfect material and finish, but the material may not be so arranged as to prove a source of profitable revenue on the trade for which the ship is intended.'*[9]

The same points were made at a gathering of northern shipbuilders and shipowners in 1930, one engineer again emphasising the importance of 'the owners' trade and needs'.[10] The complaint of the shipbuilder was that too often the owner wanted a 'stereotypical' ship that carried forward all the faults of its predecessors, or that efficiency was impaired by the reluctance of the owner to spend a little more on tried and tested technology, such as Andrew Betts Brown's proven design for telemotors, with many owners still opting for rod and chain steering control in order to save £70 on a telemotor. Brown's telemotor was developed in 1890 from an earlier design by two French naval engineers in 1887. It enabled the rotary movement of the wheel to be transmitted into linear motion in the steering gear compartment, controlling the rudder in as frictionless and accurate a manner as possible.

Even in 1905, when Robert E Froude was developing his father's work, the most senior naval officers could still decry the value of science and protest the superiority of practical experience at sea. Conversely, at the very same time Peskett was conducting extensive model tests to help shape the design of his two great liners. Yet it was only when the post-war recession spurred the search for efficiency that the mass of owners and builders finally began to appreciate the value of model testing for cargo steamers.

The accumulated published data from the UK's National Physical Laboratory testing tank helped many British builders to design an efficient hull form without conducting their own tests. By 1930, one naval architect would contend that over the previous decade 'the hull of the average tramp has been astonishingly improved' through steady progress in design.[11] As the Superintendent of the Grenelle Tank in Paris observed in 1929, the lessons of theoretical hydrodynamics could be applied only following experimental verification through the intermediary of the naval architect, utilising hydrodynamics, model experiments and empirical observations. Although scepticism on the part of some owners and builders remained, by the 1930s model tests were becoming an established part of the design process. More than 20 tanks had been opened worldwide, and naval architects and shipbuilders were sharing data internationally through the International Towing Tank Conference. This met for the first time in 1933 at The Hague, Netherlands, with delegates in attendance from Austria, France, Germany, Japan, Italy, the Netherlands, the UK and the USA.

As an LR *Report on the Society's Operations* observed, for this period, 'the use of the internal combustion engine still constitutes the outstanding feature of the development of marine propulsion'.[12] The number of motorships over 100 tons classed by LR rose from 912 in July 1919 to 3,246 in July 1929, with gross tonnage rising over the same period from 752,000 tons to 6.6 million tons, an indication of the growing average size of the motorship. By 1930, LR's *Shipbuilding Returns* show that for the first time the tonnage of motorships under construction globally exceeded the amount of steam tonnage by 349,000 tons. Competition for orders during the depression of the 1930s stimulated technical improvements, and by 1932 the motorship was costing less than ten per cent more than the steamship to build, while showing twice the profit on most voyages.

The adoption of the motorship was boosted by the world economy's growing demand for oil, particularly as the US could no longer meet demand from its own resources. With demand believed to be well in excess of tanker capacity in 1920, there was a boom in the construction of more and larger oil tankers. Between 1920 and 1938, tankers rose from five per cent to 16 per cent of the world fleet. The demand for motor tankers not only accelerated the acceptance of the Isherwood System but fostered the development of another innovation.

For tankers, the major advantage of electric welding over traditional riveting was a much more oil-tight joint. The process had been adopted with rapidity borne of necessity during the First World War for awkward repairs – it was quicker and required less labour than riveting and it took less time to train welders, though they were much better paid than riveters. LR also responded rapidly to the challenge of assessing the new method, producing *Provisional Rules for Electrically Welded Ships* in 1918. LR classed the world's first fully welded ocean-going ship, the *Fullagar*, a motor coaster built by Cammell Laird in 1920, classed ✠100A1, with the note, 'Electrically Welded, Subject To Biennial Survey – Experimental'.

However the shipbuilder made a heavy loss on the contract, which discouraged further progress until the 1930s. Partially welded tankers were built in Germany and Sweden, followed by the UK's first all-welded tanker, the oil lighter *Peter G Campbell*, in 1933. Although the cost of construction remained greater than riveting, the benefits included lighter hulls, greater deadweight from a given size of hull and reduced drag. The Admiralty encouraged the use of welding in warships during the 1930s, but Britain's conservative shipowners and shipyards resisted it during a downturn in the industry, and it would progress little further until another world war. In welding, however, there were the seeds of the first shift in the construction process of shipbuilding, not only in the fewer men required for a welded ship, but also in the place welding would have in the development of prefabrication, and the erection of structures and sections away from the traditional shipbuilding berth.

European shipbuilders quickly exploited these new trends, investing more heavily in the development of the diesel engine, making it cheaper to build in Europe. German and Scandinavian yards in particular embraced welding more quickly than British yards. The Scandinavian-built motorship won high praise for its quality and economy: 'she is invariably well-built, less conservatively designed than many British ships, and very reliable'.[13]

Like some British operators, Japanese owners were stimulated to take up the motorship in order to meet the competition. The Osaka Shosen Kaisha (Osaka Mercantile Steamship Company, OSK) developed a fleet of fast motor liners on the Yokohama–New York route via the Panama Canal, completing the voyage in a record 25 days in August 1930. The ships proved profitable, countering the received wisdom held by British cargo liner operators, that speed was unimportant. This helped Japan to build up the fourth-largest merchant fleet by 1939. Maritime historian Laurence Dunn noted that this underlined the supremacy of the cargo liner in world shipping, accounting for 23.5 million gross registered tons in 1925, by comparison with 7.5 million for the tramp fleet.

The Norwegians capitalised most on the advantages of the motorship. Their success in achieving a leading role in the world tanker market also spurred on others who had been tardier in doing so. They were able to place orders for new tankers thanks not only to substantial credit from the shipyards but also to long-term time charters secured in advance from the oil companies. Motorships in the Norwegian merchant marine accounted for 16 per cent of the world motorship fleet in 1920 and 18 per cent by 1939. By 1925 Norway had more motorships than the US, and counted as the second-largest fleet in the world, behind the British. In 1939 motorships made up 62 per cent of the Norwegian fleet. In terms of world tanker tonnage, it was calculated that Norway accounted for 24 per cent by 1938, compared with 36 per cent for the British.

More than half of Norway's tanker fleet was secured against long-term charters, and it was these that enabled many owners to survive the drop in demand for oil that came with the economic slump of the 1930s. Norwegian owners could also see the advantages of the all-welded tanker, for the first such ocean-going vessel, the 2,440 dwt *Moira*, was completed by the Tyneside yard of Swan Hunter & Wigham Richardson for Norwegian owners, Marna of Oslo, in 1935. Decisions were driven by commercial considerations. When the shipping firm Odfjell ordered a new tanker in 1937, it was only after considerable research, and upon concluding that 'such ships provided new business opportunities'.[14] For Thowsen and Tenold, 'In the 1930s Norwegian shipping enterprises represented the most dynamic and innovative elements in international shipping, and the Norwegian merchant fleet gained international influence and respect.'[15]

The success of the motor oil tanker could not have been achieved without corresponding improvements in port infrastructure. For example, the leading export harbour in the East Indies in the 1930s was the complex built at Palembang in southern Sumatra, with its pipelines, storage tanks, refinery and jetties. In the UK the port of Avonmouth was developed downstream of Bristol, on a larger site with easy rail access and suitable deep-water approaches, specifically to receive oil imports. In London the port authority responded by extending the river limits for the carriage of petroleum by building two oil terminals on the north bank of the River Thames. The rise in trade in other commodities had a similar impact on some ports. Singapore, for example, invested heavily in its port facilities in 1908–1917 and 1934–1937, mainly to handle the huge growth in rubber exports.

As for ports and harbours in general, there had been a change of thinking in the early years of the twentieth century about how best to accommodate more and bigger ships, with dock engineers like Frederick Palmer and John Wolfe Barry advocating long, straight quays, giving the flexibility to host new generations of ships and helping to speed up discharge and loading to minimise expensive time spent in port. As it turned out, the downturn in trade between the wars removed the pressure from many ports although not all of them used the opportunity to plan ahead. By the 1930s most ports in developed countries were using bulk handling for cargoes such as grain, coal and oil, but general cargo still demanded repeated manual handling. Cheap labour and the resistance of labour to change hindered the introduction of time-saving devices such as platform trucks, mobile cranes and forklift trucks, which first appeared in American ports in the 1930s. Port authorities were also reluctant to invest in new sheds and wharves, inhibiting the most efficient use of mechanical handling equipment. In developing parts of the world the same pressures applied. The port of Bangkok failed to keep pace with the size of ships, and by the 1920s half of the country's imports were being trans-shipped to lighters, a significant cost for shipping. This led to plans for dredging and widening the channel approaches as well as building a new deep-water port, Khlong Toei, on which work began in 1939.

The search for efficiency precipitated by the difficult times for shipping in the 1920s and 1930s, which had seen the further development of the marine steam engine, the rise of the motorship and revived research into welding, saw the average size of cargo vessel increase to take advantage of economies of scale. Between 1920 and 1939, a ship's average size had increased from around 1,800 tons to more than 2,200 tons. At the same time the typical steam cargo liner increased its deadweight carrying capacity from some 6,000 to 7,000 tons in 1914 to 8,000 to 9,000 tons in 1928.

While a typical cargo vessel in the early 1920s was the LR classed 7,896 grt steam turbine-powered *London Mariner*, the motorships *Tai Yang* of 1929 and *Glenearn* of 1938 were 9,307 grt and 9,784 grt respectively. The main development as conditions improved after the war was that more owners became interested in taking advantage of the improvements in ship design and marine engineering that had been accruing during the depression, leading to the launch of more efficient ships in the late 1930s.

Recession also saw the beginnings of an interest in automation. This was linked with long overdue improvements in navigation systems. Admiral Sir John Cunningham, looking back to his time as a young naval officer at the turn of the century, recalled that 'we had but few of the instruments which the modern navigator regards as *sine qua non*. We had, in fact, little better equipment than that which was used by Prince Henry the Navigator in the fifteenth century, and had to rely mainly upon the magnetic compass, the hand-lead and the sextant.'[16] The magnetic compass was gradually replaced by the gyroscopic compass, first invented in 1852. Although there were numerous attempts to develop the idea, it was only after 1908 that the first effective commercial products began to appear in the UK, US and Germany. Its main advantage was being able to point only true north, thus making it independent of the earth's magnetic field, and unaffected by a metal hull. Although the gyroscope was being fitted in some merchant ships by 1919, most mariners still favoured the magnetic compass. The gyropilot first emerged in 1914 from research carried out into the gyrocompass by the American Elmer Sperry. Although development was delayed by the war, this was the first attempt at an automatic steering device. The Sperry machine, nicknamed 'Metal Mike', was installed on board an oil tanker, the *J A Moffett*, in 1923. In the same year Nicolas Minorsky, an émigré Russian naval officer in the US, was working on a similar invention on board a US warship, while beginning to develop a basis for control theory. From the 1940s the gyroscope was also used to control the ship's telemotor electronically, altering the role of the helmsman. The device, however, would have to wait until after 1945 before it was widely applied, and had little impact until after 1950 when automatic steering was more widely adopted.

The gyroscope was also used as the basis for gyroscopic stabilisers fitted to the Italian liner *Conte di Savoia* in the late 1920s. The failure of these led to the development of the more effective fin stabilisers. The Italian liner had been fitted with steering gear supplied by the Scottish marine engineers, Brown Brothers, which also supplied steering gear for the vessels of Nippon Yusen Kaisha (Mitsubishi Mail Steamship Company, known as NYK). As a result, William Wallace, who worked for Brown Brothers, came across the fin stabiliser originally developed by Mitsubishi with limited success. Wallace recognised its advantages – effective at speed, relatively cheap, small, light and simple to operate – and with the shipbuilder William Denny & Brothers obtained a licence. Making use of the Denny Tank, Wallace completely redesigned and improved the Japanese version, producing the retractable fin stabiliser, first installed on the ferry *Isle of Sark* built by Denny in 1935. It was adopted by several British naval vessels before 1939 but like many inter-war innovations would only be taken up by merchant ships after 1945.

One of the most important developments in navigation was the more sophisticated maritime use of wireless. The first wireless message was sent over water in 1897, from Penarth in South Wales to the island of Flat Holm in the middle of the Bristol Channel, using Marconi's system, which was trialled over the next few years with the Italian, British and US navies. The first merchant ship to be equipped with wireless on a commercial basis was the German passenger liner, *Kaiser Wilhelm der Grosse*, launched in 1897.

# Guglielmo Marconi (1874–1937)

Guglielmo Marconi was an Italian electrical engineer famed for inventing a working long-range radio transmission network. He had always been fascinated by electricity. After Heinrich Hertz (the architect of electromagnetic wave research) died in 1894, Marconi's interest in electricity intensified after seeing Hertz's work in numerous scientific journals. Soon after, Marconi enrolled at the University of Bologna, studying under Augusto Righi, an established physicist. After a year of study, Marconi built his own electromagnetic wave device at his family's estate and successfully transmitted signals across a one-mile radius.

Marconi travelled to England, after finding the Italian Government was not interested in his research, where he found funding for his project. In under a year Marconi had increased his transmitter's radius to 12 miles and had patented it. Marconi's work received royal recognition when he transmitted a message from Queen Victoria's residence Osborne House to the Royal Yacht, *Osborne*. In 1899, Marconi's technological advancements continued, as he sent radio signals across the Channel to France.

At the turn of the century, Marconi hoped to be the first to achieve a transatlantic broadcast. Marconi's first attempts at transatlantic transmission failed, as his signal from Cornwall was unsuccessful in reaching Cape Cod, Massachusetts. To increase the chances of success, Marconi shortened the distance between the receivers, placing one in Newfoundland. On 12 December 1901, Marconi transmitted the first ever transatlantic broadcast; travelling a distance of 2,200 miles. The wireless station in Newfoundland received a faint three-dot tone, the Morse Code for S. Marconi's achievement was praised on both sides of the Atlantic and his famous signal was given the nickname 'Transmission S'.

In February 1902, Marconi tested his radio signal again, as his critics had claimed that the first had been too sporadic to be a success. Aboard the *Philadelphia*, Marconi made notes on his transmission's power and distance. He found that audio reception reached 2,100 miles (3,400 kilometres), which would mean that it was unlikely that Transmission S was effective enough to have reached Newfoundland, as it was irregularly timed. During the February tests, Marconi uncovered a significant discovery for radio broadcasting; signals travel faster at night than they do in the daytime.

Marconi continued improving the reliability and strength of his systems and in 1909 was awarded the Nobel Prize in Physics, an award he shared with German physicist Karl Braun.

With regard to shipping, only the most luxurious of vessels had radio signal capabilities. It was believed that radio equipment was too expensive and not effective enough to be on board most ships. This belief changed after the sinking of the *Titanic*. Marconi's radio systems were credited with saving 700 lives, as the *Titanic*'s SOS reached a number of ships across the Atlantic, including the *Carpathia*, which rescued survivors. *Titanic*'s two radio operators, Jack Phillips and Harold Bride, worked for Marconi and were hailed as heroes.

On 20 July 1937, Marconi died in Rome of a heart attack, aged 63. His status was solidified when the Italian Government granted him a state funeral. The following day, in tribute to Marconi, radio stations worldwide held a two-minute silence, when all broadcasts ceased.

For the big passenger ships, wireless was still seen as a novelty, utilised more to despatch the social chit-chat of the wealthy than as an aid to navigation, with wireless operators employed not by the shipping line but by the Marconi Company. Nevertheless, the literally vital role wireless could play at sea was demonstrated in 1909, when it was used to alert rescuers to the plight of the liner *Republic*, saving 1,700 lives before the ship sank. Yet once again it required a major tragedy – the *Titanic* disaster of 1912 – before it became mandatory on board all major passenger vessels. In 1929 this was extended to all vessels over 1,600 tons. Many owners had resisted it until then on grounds of cost at a time of austerity, while it was disliked by many merchant captains and naval officers on the grounds that it undermined their authority and restricted their independence. In time, this attitude changed as one former Radio Officer or 'Sparks' recollected:

> *The navigators valued the time signals and weather reports that radio brought them. In the event of illness or accident, advice from the shore or ships carrying a doctor became available. The facility for obtaining information from the shore regarding port of discharge, docking facilities, the ordering of stores and spares, in the event of engine failure technical advice, the exchange of social communications between the mariner and family ashore and unofficial information such as the football results on a Saturday night, all helped to bring about the acceptance of 'Sparks' as a member of the ship's crew. Later, with the introduction of radio direction finding, 'Sparks' had a direct involvement in navigation, and in dense continuous fog, played a vital role in the safe passage of the vessel.* [17]

Radio direction finding had been installed on board the *Mauretania* in 1912 but was only gradually accepted for merchant ships after 1918. It became compulsory on all British ships over 5,000 tons in 1931, although it was never very reliable and improvements came only when war once again loomed closer in the late 1930s.

The system that would become Decca Navigator was devised by a US radio engineer, W J O'Brien, in 1937, and was adopted by the Royal Navy, although civilian use would not commence until after 1945. The system that became known as Loran also began in the US in 1940, conceived by Alfred Loomis, and the first transmitting stations were set up along the Canadian coastline in 1942.

The reluctance of owners to invest and the antipathy of masters towards a device they regarded as undermining their authority and restricting their freedom of action meant that the gradual extension of wireless to most merchant ships in the years following the sinking of the *Titanic* was achieved only as a matter of international regulation. Tragedy forced a change in the way safety at sea was governed. The scale of the *Titanic* disaster brought an end to the bilateral agreements favoured by Britain as other nations, notably the US and Germany, pressed for a more wide-ranging international conference on safety. The first International Conference on Safety Of Life At Sea (later known as the International Convention for the Safety of Life at Sea, SOLAS) was held in 1913 and laid down the template for regulating maritime safety still followed today. The proposals of the 1913 convention covering passenger ships proved difficult to implement in practice, and the intervention of war postponed their eventual revision until the 1929 conference. The changes covered matters such as lifeboats, watertight compartments, fire prevention and measures to ensure the ship remained afloat after damage. They were based on the work of the British Bulkhead Committee, 1912 to 1915, chaired by the shipbuilder Sir Archibald Denny, whose members included marine engineers, naval architects and representatives of the classification societies.

A concerted attempt to harmonise international load line regulations had been thwarted by the First World War. This was revived only in the late 1920s, leading to the first International Load Line Conference in London in 1930, with 29 maritime nations reaching agreement on uniform regulations.

The first International Load Line Convention came into effect in 1933 and was applied widely throughout the world. Nations signing up to the convention authorised the seven major classification societies to assign load lines on their behalf, although LR handled the lion's share. In 1939 the societies held their first international conference, attended by the American Bureau of Shipping (ABS), Bureau Veritas (BV), Det Norske Veritas (DNV), Germanischer Lloyd (GL), Lloyd's Register (LR), Registro Italiano Navale (RI) and Teikoku Kaiji Kyokai (TKK, now known as Nippon Kaiji Kyokai, ClassNK) where agreement was reached for further cooperation between the societies.

This was one indication of the way in which the societies were developing mutual relationships. LR had pioneered one of the first reciprocal agreements between societies with Veritas Austro-Ungarico in 1907, renewed after the First World War with its successor, RI, the Italian classification society. Such agreements became common, although initially they were also used as a defensive response to LR's dominance. In 1916, ABS rejected a merger with LR, instead forming reciprocal agreements with LR's UK rival, the British Corporation for the Survey and Registry of Shipping (BC), RI and TKK between 1917 and 1919. BC would give also valuable early guidance to TKK, as the latter developed its classification role and published its first *Register* in 1924. Later on LR also gave TKK a copy of its *Rules* which they were able to adapt for their own use.

LR was extending its international involvement. Between 1926 and 1930, surveyors supervised 24 merchant ships built to class by the Leningrad State Shipbuilding Trust. From 1916 LR also established a series of National Committees, which aimed to establish 'a great degree of mutual co-operation, a freer inter-change of thought and service among the nations'.[18]

The societies kept pace with the limited technological advances of the inter-war years. ABS approved the use of welding for fabricating major machinery components in the early 1930s, and its 1936 *Rules for the Classification and Construction of Steel Vessels* were among the first to approve welding for all parts of the hull. In 1920 LR had formed the Lloyd's Register Staff Association (now known as the Lloyd's Register Technical Association, LRTA) for the purpose of 'the advancement and dissemination of knowledge in Shipbuilding, Marine Engineering and other matters of technical interest'.[19] Surveyors and other members of LR presented regular papers on a wide range of subjects, often showing the forward-thinking character of the Society, such as the paper on the electric propulsion of ships delivered in 1931–1932. These papers were published and became 'a means of storing some of the experience of the past and disseminating knowledge of present practice'. LR continued to appoint men of the highest calibre to senior posts, such as successive Chief Ship Surveyors Westcott Abell and James Montgomerie and successive Chief Engineer Surveyors James Milton and Stanley Dorey.

LR also extended its involvement in education. By the early 1920s, the Society was offering 23 scholarships, covering degrees in marine engineering and naval architecture at the universities of Durham, Glasgow, Liverpool, Michigan and Tokyo as well as the Massachusetts Institute of Technology (MIT). Michigan and the MIT had become the leading institutions in these fields in the US, alongside the apprentice schools operated by the largest shipyards, which also taught their draughtsmen elementary naval architecture. The Institute of Marine Engineers had first become involved with LR in 1908 and three of LR's scholarships were awarded through it. The INA too fostered educational activity, administering the scholarship in naval architecture set up by Benjamin Martell in 1901, and later actively encouraging employers to send their best apprentices on degree courses.

Things were changing in the shipyards. By 1914 one shipbuilder would observe that the time had passed when a shipyard might produce a ship without a contract, confident in the knowledge that with little alteration it might suit any buyer. The relationship between naval architect and marine engineer was becoming closer.

In 1900 Sir William White had written that in their collaboration on ship design, 'the naval architect and the marine engineer have a joint interest, although each has his independent responsibility'. The engineer took care of the design and manufacture of engines, boilers and propelling machinery, while consulting the architect over propeller design and supplying data on matters such as the ratio of weight to power of the propelling machinery and the rate of fuel consumption. In addition marine engine builders often designed and made cast-iron propellers for low-powered ships. In 1900 White wrote in *A Manual of Naval Architecture*, particularly in relation to naval vessels, that 'The naval architect has to embody these particulars as part of a design which shall fulfil specified conditions of speed, coal endurance and carrying capacity, while provision is made for structural strength, stability and sea-worthiness.' Stability, strength and handling or manoeuvrability too were the responsibility of the naval architect. [20]

Advances in research were also being made within the industry. By 1914 many marine engineering firms were running their own metallurgy laboratories, with research a continual process. This helped to produce stronger steel to cope with higher steam pressures, stronger iron to meet the demands of superheated steam and diesel engines, and bronzes for propellers. There was more investment after the war. British engine makers, most producing diesel engines either under licence from their European counterparts, or from Doxford's very successful and widely licensed design of opposed piston diesel engine, were expected to invest not just in metallurgical research but also in better machine tools in order to comply with the high standards set down by the licensors. The industry's own research associations, part-funded by the government, were also having an impact and Charles Parsons praised the way in which they were helping to translate science into practice.

In his Presidential address to the North East Coast Institution of Engineers and Shipbuilders in 1927, Maurice S Gibb made note of the plethora of educational opportunities and research facilities in the industry, with engineers being trained and the science and practice of engineering being promoted in engineering colleges, technical institutions, chemical and mechanical laboratories. But he also expressed a feeling among practitioners that the full potential of these opportunities and facilities was not being realised in industry. 'It is to the wider application of science that we look to enable the cost of production to be reduced, the quality to be improved and the output to be increased.'[21] It was perhaps not surprising that applied hydrodynamics was yet to be taught as part of any marine engineering or naval architecture degree course in the UK in the 1930s, whereas it was already part of the syllabus for students in Germany.

The professional societies were still playing an important role in sharing knowledge and information. Both the Institution of Naval Architects and the Institute of Marine Engineers (IMarE) were constantly discussing topics related to the technical developments of the day. With the spread of the motorship, a series of lectures was organised for IME members, and the Institute was involved with the Marine Oil Engine Trials Committee throughout the 1920s. It also collaborated with LR on research into water-tube boilers, which helped to form the new *Rules* in the early 1920s. The Institute was also extending its influence overseas, with a branch in New York, which would lead to further branches after 1945. Naval architects sustained their international collaboration with conferences organised in France and London before 1914. These were resumed only in September 1936, when the American Society of Naval Architects and Marine Engineers (SNAME) arranged an international conference in New York. Further conferences followed: in London in June 1938, attended by 14 overseas delegations, and more during the final months of peace in 1939, in Hamburg, Kiel and Berlin in June, and in Liège in August.

## End Notes

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1945-2015

# 9 Energy, specialisation and bigger ships

Post-war energy demand not only drove the development of more and bigger oil tankers but also accelerated the fragmentation of the bulk cargo trade into specialist sectors. Conversions once again tended to precede purpose-built specialist vessels. In pursuit of economies of scale, not only did ships tend to become bigger, they were also designed to be easier, and thus speedier, to load and unload. Many of these ideas pre-dated the war, showing once again how invention without demand rarely achieved success. When there was demand, as in the case of tankers, then shipyards adopted more productive methods to increase output. The new techniques were monitored by the classification societies, which also studied such issues as the impact of size on structural strength. At the same time works at many ports were needed to accommodate bigger ships, and bigger volumes of oil in particular.

All this was a symptom of the remarkable growth in post-war world trade. World seaborne trade rose from 490 million tonnes in 1948 to 3,210 million tonnes in 1973, 3,940 million tonnes in 1989 and just under 10 billion tonnes in 2013, of which 85 per cent comprised dry, liquid and bulk cargoes. A major feature of this surge was the growing worldwide demand for energy. With a bigger world population, coupled with rising incomes in wealthier nations and the use of oil in production as well as in place of other fuels, such as coal, oil accounted for 60 per cent of the increase in seaborne trade between 1948 and 1973. During that period global per capita GDP rose by nearly 3 per cent every year, encouraged by new mechanisms of international co-operation designed to foster international free trade. During the 1960s, world exports exceeded for the first time the proportion of world GDP achieved in 1913, and by 1973 accounted for more than 10 per cent of world GDP. While the oil crisis of the 1970s slowed down this rate of growth, by 1998 world exports had reached more than 17 per cent of world GDP. Growth was increasingly driven by industrialisation in the nations of the developing world, in Asia, South America and Africa. While average incomes in the industrialised countries rose by 218 per cent between 1950 and 1995, they also rose by 201 per cent in developing countries. The scale of the change over two centuries in which shipping was continuing to play such a fundamental role was illustrated by the growth of the UK's per capita GDP. If this was worth £792 in 1756, it was calculated to be £15,700 by 2000, of which a significant part of this growth had occurred since 1945. It was a phenomenon that was benefiting developing as well as developed nations.

The huge rise in demand for energy after 1945 utilised and extended existing technologies and accelerated the process of shipping specialisation. By 1970 oil and gas formed 55 per cent of all seaborne trade, although this proportion steadily declined as global output of other goods expanded, and by 2010, oil and gas made up less than a third of all seaborne trade.

In relation to newer forms of energy, specialisation often began, as it had in the past, with the conversion of existing vessels into prototype specialist carriers before the first purpose-built vessels were launched. The first bulk cargo of liquefied petroleum gas (LPG), for instance, was carried on board a converted oil tanker, the *Megara*, built in 1928 to LR class and converted in 1934. She was intended to capitalise on the higher freight rates available on the long-distance route between Rotterdam and Curaçao.

She had, in fact, been preceded by the 1,200 cubic metre capacity *Agnita*, the first ship specifically designed to carry LPG. Built on the River Tyne by Hawthorn Leslie in 1931, she was actually designed to carry three different types of cargo – sulphuric acid, gas oil and liquefied petroleum gas – with the tops of her 12 large cylindrical pressure vessels clearly visible above deck. But the *Agnita* could more properly be described as the first parcel chemical tanker, the LPG trade before 1945 never having been large enough to stimulate the design of a dedicated LPG carrier.

After the war the trade continued to be carried by converted vessels. The growth in the trade, and the unsatisfactory nature of converted vessels, led the gas firm Kosanga to work with the Danish naval architect Martin Nielsen to design the first purpose-built LPG carrier. The *Rasmus Tholstrup*, built in Sweden in 1953 with a capacity of 600 cubic metres, and operating in Northern Europe, was the forerunner of many others.

The pattern was the same in the liquefied natural gas (LNG) trade. The first ship to carry LNG had been built as a cargo ship by the US Maritime Commission at the end of the Second World War. Surplus wartime shipping seems to have played a crucial role as a catalyst for the development of new forms of carrier, providing a cheap method of entry into specialist trades. This vessel, originally called the *Marline Hitch*, was converted for the carriage of LNG under joint ABS and LR supervision in 1957 as the *Methane Pioneer*. The stimulus for this experiment was the UK's need to import gas to supplement its own inadequate resources. The issues affected classification to such an extent that LR carried out a great deal of investigation during the design phase, including research into the behaviour of aluminium magnesium alloys which was a major contribution to work in this field. Much of the approval work was pioneering and class was assigned only after careful consideration. The vessel made her first voyage from the Gulf of Mexico to Canvey Island in the River Thames in early 1959. Once again the experience gained with converted vessels was used to inform the design of the first purpose-built LNG ships. The *Methane Princess* and *Methane Progress*, to serve the UK market, and the *Jules Verne* for the French market, entered service in 1964 and 1965 respectively, to fulfil a long-term gas supply contract with Algeria. The technology proved to be very safe, with the loss of only 40 cubic metres of cargo in the half-century up to the end of 2013. By the end of 2007 there were approximately 250 ocean-going LNG carriers, with another 150 on order.

The *Agnita* was a lone example in her trade for many years. As with many other specialist trades, the small scale of the speciality chemicals industry made it possible to use general cargo ships. Small quantities of chemicals were stored either in drums or in the ships' deep tanks. But increasing post-war demand, coupled with the need to separate hazardous chemicals, made it necessary to find an alternative to the general cargo ship. Again the solution was found by the conversion of surplus wartime ships.

One of the earliest was a wartime tanker, the *R E Wilson*, converted for Union Carbide in 1948, when she was equipped with wing tanks for petroleum products and with centre tanks that could hold up to nine different chemicals. Utilising space in this way helped these ships to make the most of economies of scale, which in turn allowed speciality chemicals to be carried more cheaply. The segregation of chemicals also made it possible to trade in previously forbidden products such as phosphoric acid. In turn, cheaper rates, coupled with ease of transportation, contributed towards the growth of the trade. This made it an attractive alternative for the operators of the many small oil tankers affected by the temporary closure of the Suez Canal in 1956. The inexpensive conversion of these tankers may well have inhibited the development of purpose-built vessels. There had been a handful of purpose-built chemical tankers but their small size and expense made them uneconomic in the face of such competition. Falling freight rates stemming from this competition did, however, encourage many major chemical companies to follow the pre-war example of the oil companies and sub-contract their shipping, giving a stimulus to independent operators. This also happened with the major pulp and paper producers in relation to timber.

The continued growth of the chemical industry, thanks in part to cheaper seaborne transport and the success of the tanker operators, led to a new generation of purpose-built ships. Learning from the experience of their converted predecessors, these were equipped with more and bigger easy-to-clean stainless steel tanks suitable for both corrosive cargoes and purer cargoes, such as vegetable and other oils. Today the modern chemical tanker is a flexible vessel, capable of handling hundreds of different products from solvents and lubricants to wine, and operating on a variety of routes.

The example of the *Agnita* showed how a better commercial opportunity could encourage operators to take up and develop innovations that had appeared some years before. It was a lesson that applied to dry bulk cargoes as well as oil, gas and other chemicals. The volume of dry cargo carried on the world's oceans also grew significantly after 1945, with the trade dominated by iron ore, coal, grain, bauxite/alumina and phosphates, which accounted for around 40 per cent of all dry cargo. By the early 1980s, oil, iron ore, coal and grain made up two-thirds of all seaborne trade.

The first combination bulk carrier, the ore-oil carrier *G Harrison*, had appeared in 1921, an idea based on the eternal aspiration of shipowners to fill their ships with cargoes on every leg of a voyage. Again it was only after the Second World War that other combination carriers were developed, the pioneers being the Swedish ore-oil ships *Rautas* and *Raunala* in 1945–1946. With a high-density cargo like iron ore, most of the hull volume was given over to water ballast tankage. Once again the search for greater efficiency led instead to the development of a new ship type, the oil-bulk-ore (OBO) carrier, the first successful example being the *Naess Norseman* built to LR class in 1965. This too had its limitations, since contracts providing the right balance of cargoes for every voyage proved difficult to secure. While in theory they could operate a triangular trade (ore-bulk-oil), in practice they could make more money switching between oil and dry bulk markets, whichever had the higher freight rates. A fleet could bid for contracts of affreightment. Tank cleaning was a problem if cargoes changed frequently and as a result most owners preferred instead the simpler management of dedicated tankers or dry bulk carriers.

Bulk commodities, transported in volume over long distances, were better suited to specialisation than break-bulk goods as demand increased and output grew. The pattern tended to be the identification of an emerging opportunity by commercial operators, who tested the water as inexpensively as possible through the conversion of existing vessels, often adopting existing technologies before using this experience to help in the design of more efficient purpose-built carriers as the time came to replace wartime tonnage.

The modern dry bulk carrier also drew on the example of a pioneering pre-1939 ship. This was the motor vessel *Silurian*, built in 1924, at 6,903 grt the largest single-deck ship in the world at that time, equipped with five large holds and six large hatches, making her easy to load and unload. She in turn had drawn on the example of the large single-deck sailing ships, which had carried cargoes such as coal, nitrates and ore. She was followed by the even larger Swedish-built single-deck ore-carrying motor vessels *Amerikaland* (7,215 grt) and *Svealand* (7,185 grt), financed by long-term charter to the Bethlehem Steel Corporation. These vessels remained unique until after the war, when the limitations of wartime bulk cargo vessels became apparent. The breakthrough came with Ole Skaarup, a Danish-American shipowner, who adopted existing technology, the hoppered holds long used in short sea colliers, to create the first modern bulk carrier, *Cassiopeia*, built in 1956. With large holds and wide hatches, sloping wing tanks and bulkheads, cargo-handling was transformed, speeding up time in port. She became the template for many similar vessels as wartime tonnage was replaced.

The search for easier ways of handling bulk cargoes also led to the open-hatch bulk carrier, which was designed to offer direct access to the hold through hatches extending the full width of the ship, and could have gantry cranes fitted for cargo-handling. This was the brainchild of US naval architect Robert Herbert, whose six-hold, three-gantry crane ship *Besseggen*, built in 1962, dispensed with the slow, complex lifting process previously used for heavy rolls of newsprint, saving expensive time in port. This design was used for ships carrying a variety of similar cargoes, such as packaged timber, wood pulp and steel coils, and the basic concept has endured to this day.

The post-war single-deck bulk carrier, in essence a concept dating back to the sailing bulkers of the late nineteenth century, remained largely unchanged after 1960. *Rules for Bulk Carriers* were introduced in 1963, when these ships were first listed by LR as a separate type. Numbers and tonnage grew steadily, from 1,304 ships of nearly 17 million gross tons in 1964 to 4,886 ships of nearly 143 million gross tons in 2000. The bulk carrier had become the workhorse of the oceans, and, for author Nick Tolerton, 'absolutely indispensable to world trade'.[1]

The growing size of many of these specialist carriers was driven by economies of scale. A larger ship made it possible to carry more cargo more profitably, less expensively and with proportionately fewer crew over the longer distances required. The impact of the search for economies of scale was most evident in the vessel delivering the source of energy most in demand, the oil tanker. In addition, the development of the oil fields of the Middle East and the post-war relocation of refineries from producer countries to consumer countries, lengthening voyages between source and markets, also made larger vessels viable. This was accentuated by external events, notably the Korean War from 1950 to 1953, which placed a premium on oil supplies, and the closures of the Suez Canal in 1956 and 1967. The latter boosted bigger tankers, since the only alternative route was now via the Cape. These events also highlighted the advantage of shipping as much oil at once. By 1949 some tankers had already doubled in size to 29,000 dwt, rising to 44,000 dwt by 1954. In 1957 the *Universe Apollo* was the first tanker in excess of 100,000 dwt. Historian Glenda Rosenthal notes that 'In June 1967, there were no tankers in service exceeding 200,000 dwt and orders for tankers above that weight stood at only 15.6 million dwt. By the end of 1971, the number of tankers over 200,000 dwt had jumped to 45.6 million dwt in service and 75.6 million dwt under construction, or 85 per cent of all tankers being built'.[2] By 1972, while the average ship had doubled in size since 1950, tankers and bulk carriers had increased in size tenfold.

The demand for larger tankers became so great that mass production was the only way shipyards could cope. No longer was it the owner who told the builder what was wanted; instead it was the builder who told the owner which standard designs were available.

The technology to facilitate this had been expanded during the Second World War: the *Ocean* and then the Liberty ship programmes, started in 1940–1941, depended on welding techniques to produce a standard design that could be repeated readily for the speedy replacement of lost tonnage. Inevitably, the rapid introduction of the mass production of welded ships showed up flaws through some structural failures like brittle fracture, but further research, which continued after the war, found the solution in advanced steel composition, better structural design and higher standards of welded construction.

LR played an important part in this research both during and after the war. The Ship Welding Committee established by the Admiralty during the war included LR Chief Ship Surveyor James Montgomerie and his eventual successor, Rex Shepheard. Research continued after the war with LR working with BC and the Welding Council. Under LR surveyor Geoff Boyd, several major studies led to significant improvements in ship steel, resulting in revisions to the *Rules* and notch tough steel standards that were agreed internationally. The LR approach can be seen in the papers presented to the Royal Institution of Naval Architects (RINA) by Boyd and Bushell in 1961 and published by Buchanan, Jensen and Dobson in 1969. Although brittle fracture remains a problem in cold temperatures, this work ensured that it was much better understood and guarded against. It also led to *Rules* requirements to ensure that ship structural steel was suitable for welding.

During the course of this work, LR had sponsored the development of radiography for quality control in the use of welding. These improvements were incorporated within LR's revised *Rules* governing welding, issued by LR in 1949. By then, welding had become a proven technology. As a cheaper and more efficient method of constructing lighter, more cost-effective ships, welding would be essential in paving the way for the prefabricated construction that made commercial mass production possible. This was further developed when the Swedish A/B Götaverken yard in Gothenburg introduced the conveyor method of construction in 1963, with the building hall accommodating only one section of a vessel at a time. That year, LR classed the ore carrier *Laponia*, the first vessel to be built in this way.

Ships of a size never before seen set new challenges for naval architects, marine engineers and classification societies. As early as 1954, LR was studying the structural problems arising from larger ships, based on a careful analysis of survey reports. The Society soon found that its *Rules* were proving too inflexible and unable to keep up with the pace at which ships, and in particular tankers, were increasing in size.

In 1959, after much research, LR changed the way it formulated the *Rules*, dispensing with tables in favour of formulae which could apply to all sizes of tanker. The Society's *Annual Report* for that year noted that 'the new *Rules* will encourage designs having favourable strength characteristics, and will allow greater flexibility in application'. Other problems ranged from the reduction in cargo capacity caused by the use of thicker steel plating to cope with increased stresses, to the proper assessment of the structural strength of big ships. Complex analysis of crankshaft stresses became necessary as engines developed greater powers, sometimes resulting in failures. LR took a keen interest in understanding crankshaft behaviour – Dorey had presented a major work to the North East Coast Institution of Engineers and Shipbuilders (NECIES) in 1939. The calculation of torsional vibration became a key element of the approval of propulsion systems, with the development of software in the 1960s by Inns and Chartan. Based on its records, LR reported to the Institute of Marine Engineers (IMarE) in 1964 on factors affecting the life of crankshafts and undertook a major experimental programme to determine stress concentration factors at the LR testing laboratory in Crawley. The results and a calculation method developed from existing software were published in 1978.

Although the class societies agreed standards for bending moments and longitudinal strength, the weakness in existing methods was shown up in the case of the first super-size tanker classed by LR, the 190,000 dwt *Myrina*. Built in 1968, she required considerable panel stiffening even though strain gauges had been fitted to internal tanks during testing. This was a perplexing problem solved only with the continuing development of computer technology to carry out complex calculations in, for instance, the application of finite element analysis. Transverse strength had not been fully assessed previously. This made a huge difference and by the early 1970s LR could report that 'in recent years we have in fact learned how to measure almost anything anywhere in the world, and at short notice'. Later, using data analysis also helped LR to assess quickly and effectively trends in defects among classed ships, as well as to appraise ship plans, including the primary strength of ships. There was also a programme to review the records of service failures on a more rigorous basis.

The new construction methods were adopted most quickly and effectively by Japanese shipyards, which soon led the world in tanker building. There were several reasons for this. First, Japan itself relied on imports of oil, as well as other natural resources. Second, Japanese shipyards were rebuilt after the war, adopted modern equipment, techniques and working practices, and were more receptive to innovation. Third, Japanese shipbuilding benefited from the foresight and investment of US shipowner Daniel K. Ludwig whose *Universe Apollo*, built at Kure in 1958, was the first 100,000 dwt tanker. Ludwig invested in Japan after failing to find a US shipyard willing to build the larger vessels he wanted. Securing excellent terms on a leased Japanese naval shipyard, he took advantage of cheap Japanese labour and initiated prefabrication. This led to the fourth reason for Japan's success – the authorities insisted that the new technology in place at Kure should be shared with other yards, thus transforming Japanese shipbuilding.

By the mid-1950s, tonnage ordered by overseas owners, especially by Greek shipowners, had already outstripped domestic orders. Japanese shipyards developed a series of standard designs, which might constrain some owners, but most owners benefited once again from economies of scale, which handed owners the advantages of lower building costs, shorter delivery times and high technical standards. From the 1960s, with the decline of UK shipbuilding, Japan became the dominant shipbuilding nation for nearly half a century (by 1965 it was producing 44 per cent of the world's tonnage) and its naval architects and marine engineers were responsible for numerous design improvements, from a less resistant hull form to lighter diesel engines.

Ludwig recognised the advantages of economies of scale to be gained from building larger tankers. A tanker twice as long cost four times as much to build but increased its earning capacity eightfold, while a ship four times as large needed only three times as much power. Clearly, this was also rapidly appreciated by Japanese shipowners as they placed orders for larger and larger tankers and carriers to meet the demands of Japan's resurgent economy. The 132,000 dwt *Nissho Maru,* built by Sasebo Heavy Industries in 1962, benefited not only from the lower cost of more efficient building techniques, but also from lower fuel consumption and fewer crew. By 1964, LR was considering plans for tankers of 160,000 dwt and bulk carriers of 80,000 dwt. The new supertankers, either Very Large Crude Carriers (VLCCs) or, if above 320,000 dwt, Ultra Large Crude Carriers (ULCCs), included the Royal Dutch Shell *Batillus* class approaching 554,000 dwt, built in 1976 by Chantiers de l'Atlantique, St-Nazaire, France. In 1978, the 402,934 dwt *Nai Genova* and 409,400 dwt *Nai Superba* became the two largest ULCCs classed by LR to that date. Almost 25 years later, the four *Hellespont* sisters, of over 441,000 dwt and 380 metres length overall, three of which were launched to LR class between 2001 and 2002, were the last generation of ULCC to be built.

The largest supertanker ever built, *Seawise Giant,* had been commissioned in 1979 and after an additional cargo section was added in 1980 measured a massive 564,763 dwt with a length overall of 458.45 metres. Size placed restrictions on where the supertankers could operate and many of the longer ULCCs were scrapped at a relatively young age or converted to Floating Storage and Offloading (FSO) units, the normal size for tankers averaging 300,000 dwt.

ULCCs were also being built in the emerging shipyards of South Korea, which was already beginning to rival Japan as a leading shipbuilding nation. South Korea's yards, modern and up to date, built from scratch, backed by strong financial interests, quickly built up a significant share of the world market during the 1960s and 1970s. One of the first of these shipyards was the giant Hyundai yard at Mipo Bay, Ulsan, soon followed by others, such as Daewoo Shipbuilding & Marine Engineering Co. (DSME) and Samsung Heavy Industries (SHI). These two nations would dominate world shipbuilding for the rest of the century, constructing a wide variety of ships.

By the early 1990s South Korea had taken over from Japan as the world's biggest shipbuilding country but these two nations were already facing growing competition from the new Chinese yards being developed. China invested heavily in shipbuilding in the new millennium with the overt aim of leading the world, and by 2010 its many yards had a capacity of 13 million dwt across all classes both new buildings and repairs. By 2015 South Korea was still the foremost shipbuilding country, followed by Japan and China, all three nations accounting for over half the world's output.

The ever-larger ships being built in these emerging shipbuilding nations, specialising in the carriage of bulk commodities, were the continuation of a tradition first begun with the new technologies of the nineteenth century, exemplified by the advent of the steam collier. As with those early pioneering vessels, their success was linked with the continuing development of supporting infrastructure. Major ports, often as a result of intense pressure from oil companies, carried out significant extension and development programmes. With the relocation of refineries, chemical and petrochemical plants alongside them, these ports became industrial complexes. Rotterdam, for instance, became the biggest port in the world by 1962, and was one of Europe's three major pipeline terminals, with oil accounting for 60 per cent of its income.

As with the steamship, some ports proved incapable of the improvements needed to accommodate super-size oil tankers, but trans-shipment terminals were established, enabling oil to be distributed by smaller tankers. Bantry Bay (Ireland), for example, accommodated tankers of 300,000 dwt, whose draught was simply too deep for entry into the North Sea ports. Although trans-shipment was an added cost, it was economic for valuable bulk cargoes like oil, thanks to the falling ocean freight rates made possible by bigger volumes and bigger tankers. The growth in the size of tankers and bulk carriers led to dedicated port and terminal facilities being built in many places, including Bantry Bay, Milford Haven (Wales), Antifer (France), Rotterdam Europoort (Netherlands) and in the US at New Orleans, the Louisiana Offshore Oil Port (LOOP) for oil – one of the biggest and busiest ports in the world. For iron ore: the Port of Tubarão (Brazil), Port Hedland (Western Australia) – the world's largest bulk tonnage export port – and Port Talbot (Wales) – one of only a few harbours in the UK capable of handling capesize vessels of up to 170,000 dwt. Berthing these giants was aided by newly developed electronic systems.

Many specialised cargoes also developed specialised forms of handling, such as grabs, pumps, suction equipment, straddle carriers and forklifts. Ports became larger in order to handle the larger cargoes required to fill larger ships and to remain economically competitive with their neighbours. But the implementation of port developments often lagged behind the design and building of bigger ships. One important consideration for the naval architect was assessing the capacity of the ports on the trade route of any new vessel to accommodate her.

Technological changes in shipping and in the port industry have led to shortages of available land for port expansion within port cities, accentuating the demise of the traditional city port like London, in favour of more remote terminals on greenfield sites or reclaimed land, such as Felixstowe (UK), Zeebrugge (Belgium), Kobe (Japan) and Rotterdam (Netherlands), as well as expanding ports like Antwerp (Belgium) and Bremerhaven (Germany) where space was available, and the development of new international players like the Port of Tanjung Pelepas (Malaysia). It has also led to challenges for global hub port cities such as Singapore and Hong Kong, where space remains a premium as the ports lie nestled next to urban centres.

The impetus towards the development of dedicated terminals remote from traditional ports was further stimulated by the rise of the containership. Maersk, for instance, opened its first container terminal in New Jersey (US) in 1975, in response to scarce port capacity. This was the continuation of another new trend, the investment by shipping companies in their own terminals. In 1993 P&O Nedlloyd bought a 25 per cent stake in the Shekou Container Terminal (southern China). By the early twenty-first century, Maersk had become the fourth-largest terminal operator worldwide with 45 terminals. The container had a massive impact on ports and terminals, with its requirement for masses of space, deep water and specialised cranes. The ever larger containerships necessitated investment in ever larger gantries, and by 2007 there were 450 such gantries in operation worldwide, at a cost of $8 million each, representing an enormous investment by the leading container terminal operators.

To keep pace with new marine technologies, investment in new improved inland transportation links has made turnaround rapid, enabling ships large and small to spend more time at sea. In 1991, for instance, the 37,023 gt container vessel *Ever Growth* spent 272 days at sea and just 93 in port. A typical cargo liner only 30 years earlier would have spent almost half its time in port; this, plus high stevedoring costs, helped to drive containerisation – a key player in continued globalisation.

**End Notes**

[1] Nick Tolerton, *Bulk Carriers – The Ocean Cinderellas* (Christchurch, 2005) p v

[12] Glenda G Rosenthal, *The Mediterranean Basin: Its Political Economy and Changing International Relations* (Oxford, 1982) p83

1945-2015

# 10 The container revolution

An outsider seized on an old idea to create the greatest revolution in shipping since the steam engine. As a result, general cargo ships, many of them converted into the first containerships, were doomed. By comparison with other major changes in shipping, even the advent of steam, the transformation was rapid and had a huge impact on international trade, creating a global network of integrated supply chains, made possible thanks to the flexibility of the standard container and the fall in the cost of ocean transportation.

The most important breakthrough in post-war shipping was made by an outsider. The father of the containership, Malcom McLean, an American road-haulage operator, drew on past ideas to turn his vision of an integrated international sea–land transport system into reality.

As far back as 1837, another American, James O'Connor, had designed a boxcar that could be fitted with railway wheels or mounted on a canal barge. The container was ideal for the railways and was used on them in the US, UK and France, as well as by US haulage companies and several US and Canadian coastal shipping lines. In 1927, the Port of London Authority (PLA) enlarged a quay at Tilbury to cater for a nightly railway–ferry container service to Dunkirk in France.

Half a century later, Tilbury would become one of the UK's most important modern container terminals. These early attempts at containerisation were never sustained because of the failure to integrate the container with other forms of transport, crucial for its later success, and the lack of cheap labour available in many ports.

As a successful US road haulier, Malcom McLean knew all about the value of integration. In the early 1950s he was looking for novel ways of remaining competitive, overcoming highway congestion and taking on domestic shipping lines operating with cheap wartime ships. His idea was to use his own fleet of trucks and ships to operate an integrated container delivery service. He leased a terminal in Newark, New Jersey, acquired second-hand wartime tanker tonnage, and found an engineer, Keith Tantlinger, to design an aluminium container for him. In 1949, Tantlinger had designed a prototype aluminium container for stacking two high on barges, which had attracted much interest but few orders. In April 1956, 58 truck-trailer containers, mounted on their chassis, were loaded onto McLean's converted T2 tanker *Ideal-X* as deck cargo. She took five days to sail from Newark round the US coast to Houston, Texas, where a fleet of trucks ferried the containers to their destinations.

McLean was pursuing cheaper freight costs, the prime objective of every shipping operator through the ages, in order to maximise his profits in a competitive market. Once again commercial imperatives were driving innovation. McLean was not alone. Another US firm, the Matson Navigation Company based in San Francisco, was already reducing operating costs through the adoption of mechanical handling, and it was already investigating the use of containers when McLean's first shipment left Newark. Two years later Matson's first shipment left the US west coast for Hawaii. The innovation in Matson's case was the use of an IBM computer to carry out a fully simulated model of the business, the first time this had been applied to shipping.

Although bulk carriers and tankers had been steadily increasing in size since 1945, complemented by improvements in port facilities to accommodate them, the general cargo ship remained a relatively small vessel, hindered by port congestion and inefficient cargo-handling methods. These had been a barrier to innovation before the war, but rising labour and port costs after 1945 made the problem more acute. Many ports could not keep up with the growth in world trade, and became costly bottle-necks. Blue Funnel vessels in the Australian trade spent 60 per cent of their time in port, of which only 15 per cent was spent working cargoes; it could take three weeks to turn around a ship and as long as five to clear cargo from the wharves. For the Prince Line, port charges and handling costs rose from 38.5 per cent of all costs in 1939, to 51 per cent in 1946–1947, whereas all other costs had fallen or remained static. Before the war Prince Line ships had spent an average 165 days a year in port; by the late 1940s this had risen to 202.

Some shipping companies strove hard to adapt conventional ships to this situation. The Johnson Line's *Seattle* class of cargo liners, introduced in 1947, was streamlined, fast and fitted with electric deck cranes. Ships operated by Fred. Olsen in the 1950s had wider hatches, travelling cranes and side-ports, with cargo on pallets.

The need to reduce cargo handling costs was also the driving force behind the design of a new generation of cargo ships for Blue Funnel in the 1960s. But these proved expensive; British shipyards failed to deliver them on time, and they were overtaken by the containership.

The container was the response to this situation and had the greatest impact, but there were many other innovations, from specialised liquid and bulk handling systems to the roll-on, roll-off (ro-ro) ferries. The ro-ro, ideally suited to short sea crossings, carrying cars, trucks and trailers, was the most successful. An early pioneer of the type was the *Forde*, adapted from a First World War minesweeper in 1930 for the Townsend Brothers' Dover–Calais service. Other innovative ship types included the SEABEE (SeaBarge) and the LASH (Lighter Aboard Ship). The first SEABEE, the 47,674 grt *Doctor Lykes*, appeared in 1971; serving the route from the Gulf of Mexico to Europe, it was primarily a gigantic barge-carrier, which could carry 38 fully-laden barges, purpose-built for use on major rivers, plus containers as necessary. The BACAT (Barge Aboard Catamaran), which appeared around the same time, was a smaller version. The genesis of the concept had begun in 1967 with the idea of providing a water route from inland towns in England such as Leeds and Rotherham to European towns served by rivers and canals without intermediate handling of the cargo. An order was placed for the first, *BACAT 1*, which would commence a service between Hull and Rotterdam in 1974. The LASH was similar in concept to the SEABEE but designed for the open sea, and its barges were lifted on board rather than floated inside it. The first to enter service was the Norwegian flag *Acadia Forest* in 1969. None of these vessel types really caught on, finding only niche roles in specific parts of the world, partly because of the large size of the cargo unit and also because of the lack of shippers with waterside premises.

Such changes began the fragmentation of traditional break-bulk cargo shipping – the tramp ship and cargo liner trades, dividing cargo carrying into even more specialised sectors. Packaged timber was one example. Rising productivity in sawmills made it imperative to ship timber more efficiently, which led to the idea of packaged cargoes replacing individual planks. The first to arrive in the UK were landed at Rochester in 1958. Packaged timber caused as much of a revolution in the conservative UK timber trade as containerisation did for general cargo worldwide; it compelled merchants to invest in the fork-lift trucks and modern sheds needed to accommodate this much more efficient handling method. Before 1939 the typical timber cargo had been around 3,500 tons, and with packaged timber, this rose to well over 20,000 tons. By the late 1960s, almost a third of all softwood and 90 per cent of all Swedish and Finnish timber cargoes were shipped as packages. Some Scandinavian suppliers began using the new ro-ro ferries to send trailers of timber or newsprint rolls directly to UK sawmills, building sites and newspaper plants. These innovations had a direct impact on the way merchants managed their businesses; the ability to place smaller orders cut the cost of holding stock and reduced their susceptibility to volatile movements in prices.

McLean's experiment with containers was an instant success. His Pan-Atlantic Steamship Corporation began developing the concept by adopting the age-old precedent of converting existing ships. There was irony in the fact that Pan-Atlantic was turning general cargo ships, so dominant for so long, into the first containerships, which would revolutionise international trade. And it was a revolution that took little more than a decade to gain wider adoption. Pan-Atlantic's converted containerships, equipped with their own cranes for discharging onto road trailers in port, each carried just 236 containers. Containers had an international future, and in the early 1960s McLean began preparing to expand into the deep sea trades, including investing in onshore gantry cranes to increase cargo handling speeds.

It was not just McLean who recognised this future potential. In 1959 the US naval architect Doros Argyriadis travelled to speak to members of INA in London. His paper began with the sentence, 'The advantages of a containership are purely economic'.[1] He pointed out that cargo-handling charges for containers were just 17.5 per cent of those for general cargoes, while a containership took just 14 hours to load or unload, compared with four to five days for a conventional cargo vessel. This, he suggested, would have a radical impact when in most parts of the world stevedoring costs per ton far exceeded transportation costs over thousands of miles. But the big issue that needed resolving before the widespread introduction of containerships was international agreement on a standard container size.

This had already been raised in 1957 by a US marine engineer, Herbert Hall. Initially the US took the lead in setting standard container sizes, but the matter was passed to the International Organization for Standardization (ISO), which brokered a compromise in 1964 that met the concerns of European operators. Implementing the agreement proved difficult, especially since Sea-Land (as Pan-Atlantic was renamed), with 35-foot containers, and Matson, with 24-foot ones, possessed not a single container matching the proposed standard sizes. Yet remarkably quickly agreement was reached between all the parties involved, and following that agreement at a key meeting of the ISO in 1965, almost all the world's major shipping lines had by the late 1960s adopted compatible containers. To describe these containers, the short-hand 'teu' (Twenty-Foot Equivalent Unit) was adopted. There are now many sizes of container, but all are multiples or divisions of the original 20-foot size, such as 10-foot and 40-foot. The original standardised container size was 8′ 6″ high, but now there is a trend towards using high cube containers that are 9′ 6″ high, providing improved transport efficiency if fully loaded. There is also a growing trend towards the use of 45-foot containers. The other great advantage of the containership is that it can stow half its payload on deck, effectively free capacity.

In April 1966, Sea-Land's *Fairland*, another converted wartime ship, with a capacity of 226 teus, inaugurated the first transatlantic container service, between New York and Rotterdam. McLean's investment in a transatlantic service jolted other general cargo operators into action. Although rivals quickly entered the market, Sea-Land remained the largest operator until 1995, and the US remained the largest single national owner of container shipping into the early 1980s.

Many of the new containerships competing with McLean were also conversions. These included the new cargo ships built for Blue Funnel, obsolescent as soon as they were launched, and turned into very unsatisfactory container-carrying vessels restricted by limited hatchway and tween-deck dimensions. Many shipping companies, including Ocean Steamship Company, joined consortia, such as Overseas Containers Limited (OCL) and Associated Container Transport (ACT), in order to share the heavy costs of developing not just new containerships but an entire integrated transport system with supporting port infrastructure. In the US the situation was different, since many US conglomerates, recognising the potential of container shipping, had invested in container shipping lines, while government subsidies underwrote the cost of these new ships, which also benefited from shipping military stores during the Vietnam War.

The first purpose-built container vessel was Associated Steamship's *Kooringa* in 1964, although this was confined to the coastal route between Fremantle and Melbourne.[2] The first purpose-built containership to cross the Atlantic was the 1,210-teu *American Lancer* operated by United States Lines in May 1968.[3] Manchester Liners commissioned the first British purpose-built deep-sea, fully cellular containership with their *Manchester Challenge*, which inaugurated the Manchester–Montreal route in November 1968.

When OCL tackled the challenge of its first purpose-built containerships, the scale of the task was summed up by Marshall Meek, OCL's Chief Naval Architect:

> *We did not know how big the ships should be, nor what speed they should go. We did not know how many ships would be needed because we did not know how much of the existing trades would go into the ships. And most importantly of all, no one at that time knew how to construct large ships where the uppermost strength decks was to be almost completely removed to allow containers to be dropped vertically into the cell guides within the ships.*[4]

The timing was fortuitous, as agreement had just been reached on the standard international container size. OCL pioneered standard container fittings and tolerances in stowage. Following visits to US container lines, whose naval architects were happy to share their knowledge, and consultation with the classification societies (LR, GL and DNV), and the universities, Meek and his team designed the *Encounter Bay* class of containerships, which would run until 1999. *Encounter Bay* was powered by steam turbines reaching 21 knot speeds similar to previous cargo liners, and she had a shallow draught to meet the constraints of her destination terminals on the long-distance route to Australia. At nearly 28,000 grt, she was more than six times the size of the *Kooringa* and capable of carrying 1,578 teus. Between 1969 and 1970 OCL took delivery of its first fleet of six vessels, each 27,000 grt and 1,900 teu capacity to operate on the UK/Europe to Australia route.

With a new ship type, there were structural problems to overcome, with very wide hatch openings and concentrated stresses leading to renewed research into ship fatigue, particularly to ensure the integrity of all welded joints and hatch corners. The second OCL series, the *Liverpool Bay* class, entered service from 1972–1973.

Many challenges faced the designers of the class, including hull girder strength, torsional loading, bow flare and stern counter design, whipping and springing, vibration, motions control, container-securing systems and refrigerated containers. Even faster, at 26 knots, and much larger, with a capacity of almost 3,000 teus, these vessels spent 300 days at sea every year, demonstrating the improvement in cargo-handling productivity. One rival container line operator, having seen these latest vessels, simply ordered 'the same' from the same German shipyard, maintaining the age-old tradition of copying designs.

McLean, in advance of establishing his transatlantic service, had been developing an inland network of haulage companies as part of the integrated door-to-door delivery system crucial to the container's success. Developing a hinterland was vitally important for ports eager to grab a share of the new trade, and not all were successful. Manufacturers began to adapt their operations, based on the concept of intermodal freight – that is, switching containers from one form of transport to another. Almost every consumable imaginable proved possible to adapt to carriage by container, from wool and motorcycles to wine and chocolates, while finding innovative ways of filling containers more speedily took over from traditional packaging.

Traditional city ports, such as London and New York, were replaced by more distant dedicated container terminals, like Tilbury (UK) and Port Elizabeth (US), which had the deeper berths, overhead cranes and masses of space needed to handle thousands of containers. The ports that gained from containerisation were those investing early in dedicated facilities. In the Netherlands, Rotterdam, for instance, opened its European Container Terminus in 1966, while Felixstowe, previously an East Anglian backwater, became the UK's leading container port.

With the long-distance cargo route operators to Australia and Japan being among the earliest to convert their fleets to containers in order to overcome labour problems and stevedoring costs, Singapore seized the opportunity to become the major container port for South East Asia. Construction began in 1967; by 1982 Singapore was already the sixth largest container port in the world and much of its cargo was transhipped around the region. Kobe in Japan opened its first container terminal in 1967 and embarked on an ambitious project to develop a new container port on a reclaimed island, which eventually opened in 1981. Yokohama (Japan), Los Angeles (US) and Hong Kong also became major container ports. Other ports in the region invested in container facilities during the 1970s, including Port Kelang (Malaysia), Bangkok (Thailand), Jakarta (Indonesia) and Manila (the Philippines). For many Pacific nations the container boom transformed their export markets by allowing Western manufacturers to outsource operations to countries with lower labour costs.

The concentration of container activity in fewer and larger ports became a function of the way containerships operated. Expensive purpose-built ships, carrying ever larger numbers of containers, required fewer voyages, while container lines wanted their ships to spend as much time at sea as possible, restricting ports of call to one or two major ports on either side of an ocean. As a result, many ports were relegated to the status of transhipment ports, feeding containers to nearby 'hub' ports such as Singapore, which thrived as such.

Once successful standardisation had occurred and trans-oceanic services began, the impact of the container was rapid and extensive, 'The degree to which liner cargoes could be containerised surpassed all expectations'.[5] The number of shipping operators offering international container services rose from just three in 1966, confined to services from the US to Europe, to 60 a year later, offering services encompassing the US, Europe, Asia and Latin America. A spate of orders was placed for purpose-built containerships. Capacity on the major international routes increased fourteen-fold between 1968 and 1974. The resulting glut caused a slump in rates, and container lines struggled to cover their high fixed costs of terminals, ships and containers. In break-bulk cargo liners, freight rates had been based on the type of cargo itself, then per ton or per cubic metre. For containers, they became 'commodity box rates', with so much charged per container according to the type of cargo, but often irrespective of the actual weight of the cargo in each box. This often resulted in rates dipping to marginal cost levels, something that the former Conference liner system had worked to avoid by setting minimum freight rates. Now it became a serious problem, especially on the lightly loaded backhaul legs where many of the containers travelled empty. The slump stimulated further industry consolidation, and investment in ever bigger ships and more productive handling facilities. Containership capacity rose from less than 2 million tons in 1970 to 10 million tons in 1980. As Marc Levinson noted in his recent history of the container, economies of scale remained the holy grail for operators:

> *the more ships they had, the more ports they served, the more widely they could spread the fixed costs of their operations. The more far-flung their services, the easier it would be to find loads to fill their containers and containers to fill their ships. The broader their networks, the more effectively they could cultivate relationships with multinational manufacturers whose needs for freight transportation were worldwide.*[6]

The priority for containerships moved away from speed towards capacity. By the 1980s the cost of carrying a ton of cargo in the new generation of 4,200-teu containerships was 40 per cent less than in the previous 3,000-teu ships.

As these vessels grew larger, so the number of ports they served became more restricted, the vessels increasingly concentrated on those with the space and depth of water to handle them. They had outgrown the dimensions of the Panama Canal locks by the late 1980s, giving rise to post-Panamax designs, intentionally too big to transverse the Canal. Some previously well-established US container ports, like Oakland and San Diego, suffered from these limitations and fell into decline, while other better resourced ports, such as Hong Kong and Singapore, continued to flourish. Committing to the containership was expensive. The gantries required to handle the biggest ships cost $8 million each in 2008; even so, there were already 450 of these in operation worldwide. One of the most recent container terminals, the London Gateway, opened in 2013 at the huge cost of $1.5 billion, converted from a former oil terminal. The Panama Canal Authority has also invested massively in order to accommodate much bigger ships, spending $6 billion on wider and deeper sea entrances and a third set of much larger locks. The expansion project aims to double the capacity of the Panama Canal by 2016. As a result, significant changes are being made to the principal ports on both US coasts. On the eastern seaboard, Baltimore, Miami, New York and Norfolk are being enhanced to handle the much larger ships that will pass via the Panama Canal, including investment in wider-reaching cranes and the development of road and rail infrastructure. In contrast, the principal west coast ports are already equipped to handle the largest ships currently operating, but they require development of terminals and connectivity to rail and road networks in order to improve efficiency and reduce delays.

Another important part of the support infrastructure to allow this growth in containerisation has been the feeder fleet, increasingly important as containerships grew in size. The feeder fleet, operating on a 'hub-and-spoke' system, and usually to fixed schedules, has two roles. First, it collects containers from different ports and ships them to central container terminals for loading onto larger vessels, both vessels operating frequently enough to satisfy shippers; second, it carries containers between smaller ports. Often operated by specialists in short sea shipping, most of these vessels average between 300 and 500 teus in capacity, and they can be found worldwide, from the Yangtze in China to West Bengal in India. In Europe one of the largest feeder fleets is operated by Unifeeder, founded in Denmark in 1977. Originally serving Rotterdam, Hamburg, Bremerhaven and ports in Sweden, today Unifeeder carries in excess of a million teus annually in Northern Europe, the Mediterranean and the Black Sea.

By the 1970s the permanence and growth potential of the container trade had become obvious. Many major ports, and other relative newcomers, such as Rotterdam and Hamburg, Los Angeles and Singapore, New York and Oakland, were already investing heavily in facilities to handle the new ships and their cargoes. During the first full year of the containerised UK–Australia trade in 1970–1971, vessels were running at 90 per cent capacity, justifying the considerable capital expenditure. By 1970, 37 per cent of all trade from Hong Kong to the US west coast was already shipped in containers, compared with just 9 per cent in the previous year. Following the inauguration by American shipping lines of containership services between US and Japanese ports, Japan's first full containership service was started by Japan Lines on the Japan–California route in 1968. A similar service began two years later on the Pacific Northwest–Japan route.

The scale of the increase in trade was astonishing. In 1970 Rotterdam was forecasting that by 1975 the port would handle 800,000 teus; by 1992 it was handling 4.1 million teus and had become the third-largest container terminal in the world.

The first two places were filled by Hong Kong (8 million teus) and Singapore (7.5 million teus). By 2000, the figures for Hong Kong, Singapore and Rotterdam had risen to 18 million, 17 million and 6.3 million teus respectively. By now, however, new names were appearing among the leading ports, such as Busan in South Korea, taking the number three slot with 7.5 million teus, and Shanghai, in sixth place with 5.6 million teus. *Port Technology International* notes that 'the world's largest container port or busiest is closely contested by a number of ports'; the two main measures of how busy a container port is include the total cargo throughput in millions of tons and the container traffic that the port handles, measured in teus. These two measures do not yield the same rankings, but either way it is generally recognised that Shanghai moved into the number one spot in 2011 with a reported throughput of over 30 million teus, while Singapore was just half a million teus behind.[7] According to *Container Shipping and Trade*: in 2013, Shanghai maintained its position as the world's busiest container port after seeing a 3.41 per cent growth in volumes and a throughput of 33.63 million teus; Singapore was next, with an increase of 2.4 percent and throughput of 32.78 million teus; followed by China's port on the Pearl River Delta, Shenzhen, with a throughput of 23.27 million teus, which finally overtook Hong Kong as the world's third largest container port. Ninth place was occupied by Jebel Ali in Dubai, with a throughput of 13.64 million teus, a remarkable record for a port that had opened only in 1979. Today, Jebel Ali Port has the world's largest man-made harbour and is the biggest port in the Middle East.[8]

At an early stage, this phenomenon, encouraged by the collapse in shipbuilding prices in the 1970s, was enticing new entrants into the market, including Maersk and Evergreen, neither of which had owned a single containership before 1973. Scheduled ocean transport cost so little that it was economic for manufacturers of goods to sub-contract or outsource production to distant parts of the world where labour was cheaper, allowing them to arrange for products to be part-processed in one part of the world and shipped elsewhere for completion. Immense and complex just-in-time supply chains were hooked into the containership distribution network, and the traditional wholesaler, once the mainstay of many ports, was in decline by the mid-1980s. Retailers could now manage their own supply chains, with the result that consumer goods began to form an ever-increasing proportion of the containers carried at sea. By 2005 almost 80 per cent by value of all international sea-borne cargo was carried in containers. Today at any one time there are 20 million containers on the move by land or by sea.

Container shipping has become dominated by a handful of global operators, those massive enough to benefit from ever better economies of scale as shipping costs continued to fall. In 2013 the three leading operators, Maersk, Mediterranean Shipping Co. (MSC) and CMA CGM, controlled nearly 40 per cent of the total world capacity of more than 18 million teus. A number of operators were also forming alliances, such as the G6 Alliance formed in 2012. Most containership operators both own and charter ships, and almost half the containerships at sea are now chartered from non-operating owners. Port ownership has also become concentrated; one such owner, Hutchison Whampoa, operates 40 ports, including Felixstowe, which has some of the biggest container cranes in the world.

At the time of writing, in early 2015, it is estimated that the world's ports handle more than 580 million teus every year. To cope with the scale of this trade, containerships have become bigger and bigger, with the average size doubling between 1993 and 2013, when Maersk took delivery of its first 18,270 teu vessel, the *Mærsk Mc-Kinney Møller.* In January 2015, the port of Felixstowe hosted the arrival of the world's largest containership, the *CSCL Globe,* on her maiden voyage from China, which moored at a deep-water berth to unload 4,000 of its 19,100-teu cargo before continuing to Rotterdam. Plans are in hand for 22,000-teu vessels, with port and terminal operators worldwide investing in the facilities necessary to receive these larger containerships. While there appear to be few technological limitations to a continuing increase in size of these ships, nevertheless, diseconomies of scale will arise eventually, as they did with tankers, and the ports and cargo-handling facilities will need to keep pace. The major constraint for containerships is likely to be logistical trading considerations and being unable to fill much larger ships on every voyage.

With the growing size of containerships, it is also important to assess them to understand their behaviour. One of the challenges with the growing size of containerships has been increasing thickness of hatch coamings. This has led to investigations into crack arrest and welding, resulting in new rules and unified requirements to prevent brittle fractures.

The scope of the containership was illustrated by Horatio Clare in his recent book, *Down to the Sea in Ships*. The ship on which Clare was travelling, the *Gerd Maersk*, departed from Felixstowe for Los Angeles via Le Havre, Algeciras, the Suez Canal, Salalah (Oman), Tanjung Pelepas (Malaysia), Vung Tau (Vietnam), Nansha and Yantian (China), and Hong Kong, arriving in Los Angeles after two months. In Tanjung Pelepas, containers were loaded comprising, inter alia, 900 tonnes of Indonesian clothes for the US, 70 tonnes of edible fats and oils for Peru, 500 tonnes of Malaysian disposable rubber gloves for US medical practitioners, four containers of car parts for Mexico and Los Angeles, six tonnes of Cambodian trainers for Canada, furniture for Chile and El Salvador, plus 42 tonnes of Pakistani dates and 14 tonnes of Thai fireworks for the US. At Vung Tau in Vietnam, the cargo loaded by feeder ship included containers full of rubber goods for Colombia and Venezuela, furniture for Trinidad, tinned vegetables for Mexico, frozen fish for the US and Costa Rica, the Dominican Republic and Puerto Rico, 40 tonnes of sticky tape for the US, 15 tonnes of carpets and textiles, 15 tonnes of hats and caps, 10 tonnes of luggage, 50 tonnes of sports equipment, 70 tonnes of candles, three containers of ceramics and stoneware, 20 tonnes of aluminium and 300 tonnes of coffee. By the time the vessel had taken on containers in Yantian, Clare observed, 'We have loaded volumes of Chinese cargo for the United States almost beyond imagining'.[9] The only restriction is the container port facilities in the US, which at present cannot accommodate the largest containerships in the world fleet.

The container revolution took place more rapidly and had a more immediate and significant impact than the shift from sail to steam. Its global impact has been huge. As Marc Levinson wrote, 'In 1956, the world was full of small manufacturers selling locally; by the end of the twentieth century, purely local goods of any sort were few and far between'.[10] For William Bernstein, 'If international freight had been cheap before 1960, afterwards it became practically free'.[11] A washing machine can be shipped from Hong Kong to the UK for a few dollars, and a pair of shoes for a few cents. Containerisation made possible the more rapid and extensive industrial growth of China and other Asian economies, which by 2013 accounted for more than 60 per cent of the world's full container shipments.

The biggest containership operators are no longer simply shipping lines, but instead have become providers of global door-to-door integrated transport logistic services. They have the ability to influence the success or failure of ports worldwide, and hence national economies, with operators shifting from one to another as economic fortunes dictate. A study of Maersk illustrates that the business supports developing economies through the management and development of physical transport infrastructure at a local level alongside the integration and coordination of globalised production and demand, transforming local and national economies. The containership has transformed international trading, aided by more rapid modern communications, sophisticated technologies, deregulated markets and the free flow of capital. With the focus on three main regions, North America, Europe, and East and South East Asia, the ship, while vital, is now almost incidental.

**End Notes**


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[2] Malcolm Tull, 'Australian Ports since 1945', Lewis R Fischer and Adrian Jarvis (eds.), *Harbours and Havens: Essays in Port History in honour of Gordon Jackson, Research in Maritime History ,No 16* (St John's, Newfoundland, 1999) p121

[3] Marc Levinson, *The Box, How The Shipping Container Made the World Smaller and the World Economy Bigger* (Princeton, 2006) p214

[4] Marshall Meek, *There Go The Ships* (Spennymoor, 2003) p144

[5] Frank Broeze, 'Containerisation and the Globalisation of Liner Shipping', David J Starkey and Gelina Harlaftis (eds.), *Global Markets: The Internationalization of the Sea Transport Industries since 1850, Research in Maritime History, No 14* (St John's, Newfoundland, 1998) p388

[6] Levinson, *The Box* (Princeton, 2006) p233

[7] www. porttechnology.org/results/search&keywords=largest%20container%20port - accessed 8/1/2015

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[9] Horatio Clare, *Down To The Sea In Ships* (London, 2014) p118

[10] Levinson, *The Box* (Princeton, 2006) p3

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1945-2015

# 11 The decline and revival of the large passenger ship

**The jet aircraft killed off the traditional passenger liner, with the last disappearing in the early 1970s. Liner companies attempted to divert conventional tonnage to the cruise market, but the lead was taken by more entrepreneurial operators, notably the Greeks and the Norwegians. As cruising increased in popularity, converted tonnage gave way to ever larger purpose-built cruise ships incorporating new and existing technologies.**

It took just a quarter of a century after the flight of the first jet aircraft for the ocean liner to become obsolete. The ocean liners had seen off the competition from propeller-driven aircraft with their limited range, but the jet aircraft was an altogether different proposition. The first transatlantic flight by a passenger jet aircraft was made by a de Havilland Comet in 1958. Shortly afterwards, the much more competitive Boeing 707 entered service. The flight time between London and New York was reduced to less than eight hours, ten times quicker than the fastest liner crossing recorded by the *United States*.

Ironically, the first serious foray by the US into the transatlantic passenger market was made by the *United States*, also one of the last of the great traditional passenger liners. Designed by William Gibbs, the elegant liner was already an anachronism when she was launched in 1952. Gibbs, although no innovator, proved to be a superb assimilator of best practice. Welded construction, an aluminium superstructure and naval-engineered steam turbines of 240,000 shaft horsepower (shp), produced a vessel 60 per cent lighter and three knots faster in service than the previous queen of the oceans, *Queen Mary.* The *United States* had the greatest power-to-weight ratio ever achieved in a commercial passenger liner. Aluminium would continue to find favour in the superstructures of the last generation of conventional passenger ships, valued for its lighter weight, greater resistance to corrosion and non-magnetic properties. Its fundamental disadvantage, which prohibited its extensive use, was its expense. The metal's use in the *United States*, however, helped the liner to become the last traditional holder of the prestigious Blue Riband for the fastest crossing of the Atlantic, achieving a speed of more than 34.5 knots on her maiden voyage in July 1952. During trials she she was reported to have reached an even greater 42 knots.

Competition from the passenger jet aircraft killed off almost every passenger liner. The last purpose-built ocean liners intended for regular service were built in the late 1950s and early 1960s, such as the Italian Line's *Raffaello* and *Michelangelo* in 1962–1963 and Compagnie Générale Transatlantique's (CGT) *France*, which entered service in 1962. *Canberra*, the last and largest liner ordered by Peninsular & Oriental Steam Navigation Co. (P&O) for the Australian migrant trade, was completed by Harland and Wolff Ltd, Belfast, in 1961. At 45,000 grt, she was also the largest liner built in the UK since the *Queen Elizabeth*. *Canberra*'s turbo-electric machinery, developing 85,000 shp, was the most powerful installed in a British-built merchant ship for over 20 years.

Against growing competition from the airline industry, the ocean liner limped on into the 1970s, when the last of them on the longest distance routes, to South Africa (Union Castle Line), New Zealand (Shaw, Savill & Albion Co.) and Australia (P&O-Orient Line), were finally taken out of service. Holland-America had withdrawn the *Rotterdam* from scheduled services in 1968 to rebuild her for cruising, while in 1974, after just 12 years in service, the majestic *France* was withdrawn due to declining patronage. As for passenger ships sailing under the British flag, by 1979 only those in service with Cunard and P&O remained. *Canberra* was successfully adapted for cruising in 1974.

The troopship also disappeared. The Bibby Line's last troopship, *Oxfordshire*, launched in 1957, served just five years before its government contract, an original charter of over 20 years, was terminated. No longer did states have to incur the expense of keeping and feeding hundreds of troops at sea for several weeks if they still needed a presence overseas. Fewer garrisons, and the speed and cost advantages of air transport, meant that after the mid-1960s the movement of troops by ship was replaced almost exclusively by aircraft, with the exception of later conflicts like the Falklands War in 1982, during which *Canberra*, *Queen Elizabeth 2* and *Uganda* were requisitioned.

# Samuel Cunard (1787–1865)

Samuel Cunard was the son of Abraham and Margaret who settled in Halifax, Nova Scotia where they formed A. Cunard and Sons, a firm that firstly exported North American timber to most British territories and then expanded into the mail, coal, iron and whaling industries.

From the beginning of the early 1820s, Samuel Cunard assumed control of the company. After his father's death in January 1824 he decided to rename it S Cunard and Company effective from 1 May 1824, and to operate a steam ferry service in Halifax harbour. During the late 1820s, Cunard invested in more steamships, including the *Royal William*. Steamships were becoming increasingly popular and opening up new trade and routes, therefore the Royal Mail decided to seek a shipbuilder who could build the first mail steamship.

Cunard moved back to the UK and was awarded the new mail contract. He formed the British and North American Royal Mail Steam Packet Company – which quickly became known as Cunard's Line – the main partner of which was Robert Napier, who built the steam engines required for the mail ships.

Cunard purchased three ships for £55,000 in May 1839, intending to use them between Liverpool and Halifax and then to Boston and Montreal. By May 1840, the British North American Royal Mail Steam Packet Company was officially created with capital of £300,000, of which £55,000 came from Cunard. Within days, the 649-ton *Unicorn* made the first voyage to Halifax.

That August, the *Britannia*, the first steamer of that class, left Liverpool for Halifax, and then continued to Boston. The voyage lasted for 12 days and 10 hours, and the ship made an average speed of 8.5 knots. Cunard's earliest ships had a distinctive red funnel with black bands and a black top, the same colour configuration is still a feature of Cunard's ships today. Another unique factor of Cunard Line ships was their emphasis on safety. According to historian Stephen Fox, Cunard's specific orders read 'Your ship is loaded, take her; speed is nothing, follow your own road, deliver her safe, bring her back safe – safety is all that is required.' On another occasion he is quoted as having said 'No racing, no rivalry and no risk-taking'.

During the Crimean War, all transatlantic voyages were suspended with the exception of Cunard's. He also supplied 11 ships for war service. In 1859 Cunard was made a Baronet by Queen Victoria in honour of his contribution to the British shipping industry and took the title Sir Samuel Cunard, 1st Baronet. He continued to innovate and improve his services across the Atlantic and created a secondary service operating from Liverpool to New York in 1863, utilising iron-hulled screw steamers, the first of which was the *China*. Two years later, Cunard died aged 78 leaving control of the Cunard Line to his son Edward.

Since at least 1889 the operators of passenger liners had tried to maximise their efficiency by placing them on cruising duty outside the peak liner season, meeting a demand for holidays in the sun at sea or in scenic regions. With competition from the airlines, this was an avenue well-travelled by many liner companies, such as Holland-America Line and Norddeutscher-Lloyd, which headed for the US, the major world cruise market during the 1960s. But ocean liners were built neither for comfortable cruising nor for economic voyaging between multiple ports of call short distances apart; many of them were also much too large for the demand from an as yet undeveloped cruise market. These disadvantages were compounded by competition from more opportunistic rivals; in the mid-1950s, for instance, Greek operators entered the market with smaller, more suitable vessels, working the Mediterranean in the summer and the Caribbean in the winter.

The Greek operators' time in the sun was short-lived, their ageing tonnage falling foul of more stringent safety regulations, leaving a gap that was filled by entrepreneurial Norwegians. Moreover, Norwegian cruise lines entered the market in the late 1960s and early 1970s with the first purpose-built modern cruise liners since the *Empress of Britain*, which had been built as an ocean liner in 1931 and used for cruising during the winter months. Unlike their ocean-going predecessors, these vessels, such as Royal Caribbean Line's 18,400 grt *Song of Norway* (1970) and Royal Viking Line's 21,800 grt *Royal Viking Star* (1972), were not built for speed. Other shipping companies followed suit, including Cunard, although there seemed so little potential in the market, focused as it was upon a wealthy elderly clientele, that Cunard declared in 1976 that its latest cruise ship, the *Cunard Princess*, would be the last of the passenger cruise ships.

But another new company, Carnival Cruise Lines, founded by an experienced cruise ship operator, Ted Arison, had entered the market in 1972. Beginning with the *Mardi Gras* (built as the *Empress of Canada* in 1961), second-hand tonnage expressly converted for cruising, Carnival revived the market.

A decade later, its first purpose-built cruise ship was launched. When the order for *Tropicale* from Aalborg Vaerft was announced, the size of the new vessel staggered the cruise industry. The 36,600 gt *Tropicale* was conventional in layout and propulsion, and carried 1,396 passengers and 491 crew. Popular with holidaymakers, she was followed a few years later by the *Holiday* class of three vessels of 47,000 gt, making them larger than the *Titanic*. Described as 'superliners', these ships highlighted the development of the cruise market and the way in which shipping operators were once again making use of the flexibility of the metal-hulled ship to create a vessel catering for a very specific purpose. These were indeed specialist cruise ships – the term 'liner' now a misnomer – with a more radical internal layout, notably spectacular atria, main show lounge and sea view restaurants.

Each successive generation of cruise ships grew larger than the last, emphasising the importance not only of economies of scale but also size across the many different sectors of shipping. Carnival's 1987 *Fantasy*-class was 70,000 gt, powered by a diesel-electric system, with a hull designed after comprehensive model-tank testing. The latest Carnival cruise ship, the *Carnival Vista*, due to be launched in 2016, will be nearly twice the size at 135,000 gt. Yet even she will seem small beside Royal Caribbean Line's 225,282 gt *Allure of the Seas*, capable of accommodating more than 6,000 passengers. Aluminium, used in the *United States* as an aid to speed, is now often used as an aid to buoyancy, to reduce draught and to improve stability in these massive vessels. Sophisticated side thrusters and fin stabilisers improve manoeuvrability and reduce rolling.

Computer-aided design, combined with prefabricated construction, enables much larger ships to be built more quickly. Sequentially numbered sections assembled in covered berths, as well as modular cabins craned into place, each one taking less than an hour to wire and plumb, enable ships to be built efficiently. At the same time, smaller ships continue to be launched, aimed either at small-scale cruising, such as around the British Isles or on the Baltic and Scandinavian routes, or fitted out to very high standards and aimed at the very wealthiest cruise passengers.

The enormous cruising ships, monsters of the sea and often lacking the elegance of the liners of the golden age, have now become a destination in themselves. Many conform to the principle of accommodating what the naval architect Stephen Payne, OBE, described in 1994 as 'the required internal volume within the minimum of dimensions'.[1] Their boxy shape is accompanied by a shallow draught, necessary to accommodate an increasing variety of ports of call. Payne warned, however, that careful consideration was needed to prevent such designs leading to unsatisfactory handling at sea or the inability to sustain high speeds through a lack of fuel bunkering space. In catering for the hugely lucrative cruise market – 14 million people were taking a sea cruise every year by 2013 – the cruise ship was becoming almost over-specialised, its seagoing characteristics overridden by the concept of a floating hotel.

The Cunard Line brought back the ocean liner in 2003, by which time the line was part of the Carnival organisation. The 148,548 gt, 345-metre-long *Queen Mary 2* was the first purpose-built transatlantic liner since the *Queen Elizabeth 2* in 1969. Classed by LR, flying the British flag, carrying up to 4,400 passengers, and propelled by four diesel engines and two gas turbines connected to electric generators to drive propulsion motors and power hotel services, she is capable of operating all year round on the North Atlantic. Her elegant design was also a sharp contrast with the more functional appearance of the largest cruise ships. In designing such a huge ship, advantage was taken of innovatory submerged and fully rotational assemblies, azimuthing thrusters, often called pods, which both propel and steer the ship, replacing conventional multiple-propeller shafts and rudders, and intended to give such a huge ship greater manoeuvrability.

At the time of her launch, the *Queen Mary 2* was the largest passenger ship ever built – but her supremacy was soon surpassed. In 2006, the 154,407 gt cruise ship *Freedom of the Seas* was launched in Finland for her owners, Royal Caribbean International, followed three years later by the 225,282 gt *Oasis of the Seas* from the same yard for the same owners.

**End Notes**

1 S M Payne, 'The return of the true liner?', *The Naval Architect*, September 1994, p43

1945-2015

# 12 The search for cleaner fuel at sea

The search for increased fuel efficiency had a low priority during an age of abundant cheap fuel after 1945. Even so, there was research into alternatives such as the gas turbine and nuclear power, but these remained the preserve of the world's navies. Most of the world's shipping was powered by either the steam turbine or the marine diesel engine. The demise of the steam turbine came with soaring oil prices in the early 1970s, leaving the marine diesel unchallenged until a further rise in prices coincided with a downturn in trade in the early 2000s. Combined with growing concern over the impact of emissions from oil burning fuel at sea, this led shipowners to consider alternatives with lower emissions for the first time since the introduction of the motorship. Liquefied natural gas (LNG) is currently the preferred choice, often in combination with other fuels, but this is still a developing as well as an expensive technology, largely due to the cost of LNG fuel storage at cryogenic temperatures. Although diesels, gas turbines and boilers for steam turbines can all burn natural gas, most of the world's shipping continues to be served by increasingly efficient and much less costly diesel engines burning oil.

After 1945, steam turbines and diesel engines, nearly 50 years after their first appearance, had become the proven and preferred propulsion system for almost all of the world's ships. While shipowners were always seeking increased efficiencies and cost savings, fuel costs were not a high priority until the surge in oil prices in 1973. By 1959 more than 80 per cent of all new vessels were diesel-powered; one factor favouring diesel was the development in the 1950s of the turbocharger, which turned the slow-speed direct-drive diesel engine into a rival for the more powerful steam turbine.

There was a search for alternatives. The engine builder Sulzer had begun work on the gas turbine before 1939, but the first version was not produced until 1947. In that year LR was involved with the trials of the first high-powered marine installation on board a Royal Navy motor gunboat, the *MGB 2009*, converted under LR survey. But other than in naval vessels, where gas turbines were used initially to boost the power of steam turbines for short periods at high speed, the gas turbine has lacked the economic impetus for wider development other than in some modern cruise ships. While compact and lightweight, easy to replace and producing low noxious emissions, the gas turbine is costly, and less robust than the steam turbine as well as inefficient at less than maximum power, and the aircraft derivative types burn expensive distillate fuel. The gas turbine was still in an evolutionary stage by the mid-1980s when Professor R V Thompson, from the University of Newcastle, accurately forecast that a more sophisticated design might eventually 'present a viable alternative to more traditional power plants but probably in combined cycle operation and only in specialised applications'.[1]

Electric propulsion was another application for specialised vessels with a variety of power demands, although since the adoption of high power density electric motors it has been more widely employed by more ships. A paper on the *Electric Propulsion of Ships* was presented at the LR Staff Association in 1931–1932, when it must have been seen as something of a curiosity for merchant vessels, despite having been used in US Navy ships already. Diesel-electric propulsion in shipping, particularly cruise ships, is common using the power station principle whereby the diesels only generate electricity, for both propulsion and hotel loads, which can be as high. In 1986–1987 the *Queen Elizabeth 2* underwent a major refit under LR survey at the Lloyd Werft yard at Bremerhaven in Germany, where nine MAN B&W diesel-electric engines, new propellers and new equipment to capture heat expelled by the engines were fitted. The passenger accommodation was also modernised, transforming her from an ageing steamship to a state-of-the-art diesel-electric motorship, with a predicted £12 million a year saving in fuel costs for Cunard. Some ships, including a *Fantasy*-class cruise ship, were built with hybrid diesel-electric propulsion, but so few that even in 2013 this was still being discussed as an option for the future.

After the early application of nuclear energy for generating electrical power ashore and for the propulsion of submarines, which was possible as no oxygen was needed, several countries showed an interest in exploring its application to shipping. The world's first operational nuclear-powered submarine was the USS *Nautilus* (SSN-571) completed in the USA in 1955. In 1960 LR developed *Provisional Rules for the Construction and Classification of Nuclear Powered Ships*, based on knowledge and expertise gained in assisting the UK Ministry of Defence with the development of the first UK nuclear submarine, HMS *Dreadnought*, built by Vickers-Armstrongs at Barrow-in-Furness and powered by a US-built S5W reactor.

The world's first nuclear-powered surface warship was the USS *Long Beach*, commissioned in 1961. In the same year, the first nuclear-powered aircraft carrier was commissioned. The USS *Enterprise* was criticised for the huge cost of her construction, but she carried more fuel and ammunition for her onboard aircraft than conventional carriers and could remain at sea for many months as there was no need to refuel for her propulsive machinery, though she did need to replenish her aviation fuel more frequently.

The world's first nuclear-powered surface vessel was the Russian ice-breaker *Lenin* constructed at the Baltic Shipbuilding and Engineering works in Leningrad and in operation from 1959 until 1989. Yet an uncertain political climate, high costs and lack of public confidence led to only a handful of nuclear-propelled merchant ships being built: *Savannah* (USA 1959–1972); *Mutsu* (Japan 1970–1992); *Otto Hahn* (West Germany 1968–1979); and *Sevmorput* (USSR 1988 to date). The latter is an icebreaking LASH carrier and container vessel.

More recently, as shipping operators have sought more cost-effective forms of propulsion, there has been a renewal of interest in nuclear power. In 2009 the Chinese shipping company China Ocean Shipping Company (COSCO) suggested that greenhouse gas emissions might be reduced by powering containerships with nuclear reactors, but a state-funded study into the idea was abandoned in 2011 following the Fukushima nuclear incident in Japan. In 2010, LR's Chief Executive Officer (CEO) Richard Sadler had forecast that 'We will see nuclear ships on specific trade routes sooner than many people anticipate'.[2] In the same year, LR began a two-year study into the possibility of small modular reactors, with several partners including Hyperion Power Generation, BMT Group and Enterprises Shipping & Trading, with the aim of producing a concept design for a commercial tanker. LR also revised its existing *Rules*, and in 2014 published papers arising from the research study. These concluded that the concept would become viable only with the further development of nuclear technology and a more unified worldwide regulatory approach.

The supremacy of the marine diesel engine was confirmed by the oil price shock of the early 1970s. Almost overnight the steam turbine was abandoned for most new ship orders. In 1978, just 32 steamships were built; this meagre figure dwindled to eight by 1984. Steam tankers went for scrap at young ages, while some steam-powered container ships were re-fitted with diesel engines. Even though in the 1980s oil prices began to drop back from their peak, they remained high by historical standards, and there was no enthusiasm to return to steam turbines because of their relatively low efficiency and the lack of people trained to operate them. Container ship speeds dropped back from 25–27 knots to 23–24 knots or less, while tankers and bulkers remained at their traditional 15 knots, or down to 8–9 knots when under slow steaming in order to conserve fuel.

By 2000, when most container vessels at sea had been designed to travel at around 24 knots on cheap fuel, the price of oil began to rise once more. By 2008, as the worldwide shipping recession began to bite, the falling freight rates had an acute impact on operating costs, compelling owners to consider more efficient alternatives to oil. The optimum solution would have been a vessel capable of operating at a range of speeds dependent on fuel prices, but other than constantly changing a ship's propeller or using controllable pitch propellers this was impracticable. What became much more widespread was slow steaming, with many containerships operating at around 18 knots, both to reduce fuel costs (making up half their operating cost, excluding shoreside operations) and dropping the tonne-mile supply of ships in the face of reduced demand. Shipowners were beginning to consider more fuel-efficient ships, an impetus further stimulated by impending legislation as regulators pursued lower emissions.

# Rudolf Diesel (1858–1913)

Rudolf Diesel was born in Paris in 1858, to Bavarian parents. During his early childhood, Rudolf lived in Paris, but at the outbreak of the Franco-Prussian war in 1870, he was sent to live with his aunt and uncle in Augsburg. Here, Diesel's uncle suggested he study mathematics at the Königliche Kreis-Gewerbsschule. By the age of 12, he was fluent in both German and French. In 1873, he enrolled at the Industrial School of Augsburg and two years later received a scholarship from the Royal Bavarian Polytechnic of Munich.

Before Diesel could graduate, he contracted typhoid and had to delay his examinations, so he worked as an engineer's apprentice in Winterthur, Switzerland at the Gebrüder Sulzer Maschinenfabrik. Upon completion of his apprenticeship in January 1880, Diesel worked in Paris with his former professor, Carl von Linde, building a modern refrigeration unit. He also helped manage and later direct a steam-powered ice plant, becoming fascinated by fuel and thermal efficiency. As well as working with Linde on refrigeration, he developed his own projects, including fuel-efficient steam engines. In 1892, he received the patent for *Method of and Apparatus for Converting Heat into Work*.

His work started with a basic design of an engine based upon Nicolas Carnot's thermodynamic cycle, a study in which he found that 90 per cent of the energy used in steam engines was wasted. Diesel's treatise *Theory and Construction of a Rational Heat-engine to Replace the Steam Engine and Combustion Engines Known Today*, led to the invention of the Diesel engine, arguably the most significant engineering invention in history. The compression-ignition engine worked by compressing the air inside the cylinder, thus increasing its temperature, fuel is then injected into the cylinder of compressed air causing it to ignite; the gases are then expelled through the exhaust. He had already obtained a patent for his compression-ignition engine, and his patent spread from the US to Germany and France.

On New Year's Day 1896, Diesel unveiled his engine, which had a theoretical efficiency of 75 per cent but only achieved efficiency of around 45 per cent, despite Diesel's calculations. Even though he considered it had underperformed, it was a remarkable achievement for an engine of the period. It prompted thousands of orders worldwide, not only because of its efficiency but also because it was so versatile; it was used for shipping, early oil drills, factories, as well as basic mechanisms.

In 1900, Diesel experimented on the prospect of using vegetable oil as potential engine oil. He also experimented with using peanut oil and coal dust to power his engines, which became a replacement for conventional oil when prices rose in 2008.

In spite of Diesel's achievements, many remember him for the mystery surrounding his death. It is believed that Diesel committed suicide. On the evening of 29 September 1913, he travelled to London from Antwerp on the *Dresden*, but never arrived in London. He was last seen on board the ship walking to his cabin. His bed had not been slept in although his jewellery, including his watch, was left on his bedside table.

Ten days after his disappearance, Diesel's body was found by the ship *Coertsen* in the North Sea. The crew only brought aboard Diesel's belongings, which were later identified by his son, the body being too decomposed for his face to be recognised.

After his death, Diesel's engine continued to be used in different sectors. In 1924, MAN AG (Maschinenfabrik Augsburg–Nürnberg), were the first company to use a direct-injection diesel engine in an automobile. Around the same time, Mercedes-Benz produced a diesel truck, which led to its first diesel-powered car, made available to the general public in 1936.

Several alternatives were under consideration. The major shipping companies, with the most extensive fleets and the most to gain from spending less on fuel, were at the forefront of this research. In 2009, Maersk and Shell collaborated with LR on a two-year research project into the suitability of biodiesel. The Japanese operator NYK built several innovative vessels, including the car carrier *Auriga Leader*, equipped with 328 solar panels, and the containership *NYK Altair,* which recovered waste heat to supply electricity, reducing the fuel and maintenance costs of its auxiliary engines. A German company, Beluga SkySails, pioneered a towing kite system, which in trials on board an ocean-going general cargo ship was calculated under the most favourable conditions to reduce fuel consumption by up to a third.

Shipowners can meet emissions targets by either burning distillate fuel or scrubbing emissions to remove sulphur oxides (SOx) and nitrogen oxides (NOx). Another possible alternative is liquefied natural gas. One of the main considerations in opting for LNG as a fuel is availability; many of the issues were the same as they had been when motorships had first been introduced, such as ample bunkering facilities and security of supply. As a result, the European Union has proposed that LNG bunkers should be installed at all major European ports by 2020. A study on bunkering carried out by LR in 2011 underlined that while shipowners were prepared to invest in LNG as a fuel, this would still be dependent on price. Since there was a risk that LNG might prove more expensive than oil, owners were eager to hedge their bets by exploring ships with dual fuel supplies. By 2013, DNV GL was classing containerships equipped with dual-fuel systems capable of burning either oil or gas. In the same year, a Greek shipping firm took delivery of the first tri-fuel ship, the *Woodside Rogers*, powered by engines able to run on either LNG, marine diesel gas or heavy fuel oil.

The taking into account of these dual- and tri-fuel systems was one factor in designing the new generation of ships. Others included the need to have large insulated fuel tanks, to provide the same range between fuelling as for a conventional vessel. There was also a need to prevent any boil-off of gas, which alternatively could be burned in the engine, flared or re-liquefied, since this would create emissions far outweighing those of oil fuel.

Classification societies played an important part in assessing this potential shift. LR, for instance, issued its *Rules and Regulations for the Classification of Natural Gas Fuelled Ships* in 2007, revised in 2012. In 2011, LR classed the *Argonon*, the first new build LNG-fuelled oil tanker, and in 2013 the LNG-fuelled ferry *Viking Grace*. The former was limited to inland waterways while the latter, defined as the first deep-sea LNG-fuelled vessel, plied a regular route between Finland and Sweden. In 2014, LR was also invited to class a hybrid ferry, the *Texelstroom*, built by Construcciones Navales Del Norte SL, Spain, and propelled by compressed natural gas or low sulphur diesel oil, and utilising battery power and solar auxiliary power. She is intended to enter service in 2016, running between the Dutch island of Texel and Den Helder on the mainland.

This emerging technology has tended to be confined to niche areas where new regulations are most stringent or local areas where the refuelling infrastructure can be created. Nevertheless, in 2011/12 LR helped to develop an emissions-compliant design for the 'Clean Sky' class of LNG-fuelled Kamsarmax bulk carrier in conjunction with the Chinese COSCO Shipyard Group and the Greek shipping firm Golden Union. In the following year, LR also won a contract to develop operating and technical standards for LNG bunkering facilities in Singapore. In 2014, LR won the contract to class the first dual-fuel tankers built in China, due for delivery by Hudong-Zhonghua Shipbuilding in 2017.

This is only the start of the new technology. The shift to LNG once again highlights the gradual pace of technological change in shipping; it is forecast that LNG will account for just 11 per cent of all fuel used by shipping by 2030, ranging from nearly a third of the fuel mix of chemical tankers to just five per cent in containerships. In 2009, LR began a two-year joint project with industry partners Maersk Line, Shell Marine Products and Shell Global Solutions to test the feasibility of using biodiesel for marine propulsion, conducted on board the containership *Maersk Kalmar*. The results help to understand how engine performance and emissions change with the substitution of a bio-blend fuel and whether the fuel is viable.

As for the bulk of world shipping, the majority of vessels are propelled by slow-speed diesel engines connected to fixed-pitch propellers. Attempts to refine their operation have been stimulated by the cost of fuel and emission regulations; in 2010, LR's charitable arm, the Lloyd's Register Educational Trust (LRET), now the Lloyd's Register Foundation, funded a five-year research programme into emissions at the National Technical University of Athens. Diesel engines themselves have continued to undergo a process of continuous refinement, becoming more fuel efficient. One of the key trends over the last decade has been the introduction of electronic fuel injection systems delivering precision control, which has transformed the management of diesel engines. The steam turbine, on the other hand, has almost vanished. A thing of beauty for many engineering officers, elegant, smooth and quiet in operation, its thermal efficiency level of less than 40 per cent cannot match the 50 plus per cent efficiency of the diesel engine in an era of costly fuel and with trade not growing as fast as previously.

**End Notes**

[1] Professor R V Thompson, 'Future Aspects of Marine Technology', Guest Lecture, *Lloyd's Register Technical Association Papers*, Session 1984-85, p10

[2] 'Full steam ahead for nuclear shipping', *World Nuclear News*, 18 Nov, 2010

1945-2015

# 13 Technology and the seafarer

Technology was seen as a way of making ships more efficient by reducing operating costs. But while profitability was a prime concern in adopting the latest forms of automation, little account was taken of the inadvertent impact on officers and crew. Over-confidence, over-reliance and a lack of understanding on the part of the crew were all pitfalls associated with these new technologies, whatever their undoubted advantages for the operation of the ship. In addition, new systems, often monitored or controlled remotely, have diminished the detailed hands-on involvement of officers and crew with their ships. Recently there has been greater recognition of the value of human engineering in ensuring that new technologies are developed with the user in mind. Even so, given the more isolated life of the modern seafarer, a career at sea is now much less attractive than it ever has been.

Even before the steamship the aim of most shipowners had been to operate their ships with the minimum number of crew. Manning costs remained a concern after 1945 as voyage and cargo-handling costs soared – between 1939 and 1963, the cost of maintaining the fleet of Blue Funnel motorships rose from 55 to 75 per cent of total voyage costs. Fuel costs had actually fallen as a proportion, and would become a priority only after the oil price shock of the 1970s. For Blue Funnel, adopting automated machinery and deck equipment was an important means of cutting back on manning costs. At the same time the marine engineer also believed that automation should lead to greater simplicity of operation and reliability. In any event, automation and unattended machinery space had to pay its way, and no owner would install automated systems without a commercial reason. The application of automation to reduce costs was practised worldwide. As ships became larger and more automated, they required fewer crew. Crew numbers roughly halved between the 1950s and the 1970s. For instance, in 1961 the 8,000 grt Japanese dry cargo ship *Kinkasan Maru* had 43 crew; within four years the 96,000 grt tanker *Tokyo Maru* had only 29.

As systems became more sophisticated, it became possible to develop unattended machinery space (UMS) on board ship. With the increasing reliability of control systems, software and sensors, the number of vessels equipped with UMS has grown rapidly. Training for crews to understand remote operating systems is regularly provided by most shipowners. Another driver is that it allows the engineering staff to concentrate on maintenance rather than watch-keeping duties. In a competitive industry, UMS is another means of reducing crew costs, but it is also seen as a safer option. UMS, however, does not imply total remote control of all operations. It is, for example, recommended that UMS should be left unmanned for no more than 16 hours in a row; and ultimately the bridge retains control over the ship's propulsion machinery. These and other requirements, mainly governing safety, for UMS vessels were set out by SOLAS in 1974.

Technology also brought disadvantages to the seafarer. Concerns were expressed even in the late nineteenth century about the dangers of crew being overwhelmed by the management demands of proliferating and complex on-board systems. Admiral Sir John Cunningham, speaking just after the Second World War, which had seen great progress in the development of navigational aids, insisted that 'In the long run it will always be the man that counts. It is folly to rely entirely on instruments, and every navigator must take care not to forget the basic principles of navigation.'[1]

Cunningham may well have had in mind the drawbacks of radar as it was taken up by merchant shipping at the end of the war. It first appeared on British merchant vessels in 1944 although purpose-designed systems emerged only after war had ended. Intended as much an aid to avoiding collisions as for navigation, early radar proved instead a contributory factor to numerous collisions. One of the most notorious was the collision between the two transatlantic passenger liners *Stockholm* and *Andrea Doria* in fog in 1956, which caused the latter, recently completed to LR class, to sink with the loss of 46 lives. Relying on radar in conditions of reduced visibility gave officers on watch a false sense of security, encouraging them to undertake manoeuvres they would never have attempted otherwise. It also transpired that in numerous cases radar occupied so much of the attention of officers on watch that they lost sight of the wider navigational picture, again leading them to make inappropriate decisions contributing towards collisions. Such incidents became so regular that the phrase 'radar-assisted collision' entered common usage. Remarkably, 70 years after radar was first adopted for merchant shipping, and despite its increasing sophistication and accuracy, radar-assisted collisions still occur. Nevertheless, radar and other navigational developments have undoubtedly had many more advantages than drawbacks. After the war Decca Navigator and Loran, particularly Loran C, became the standard systems of radio navigation worldwide until they were overtaken by satellite navigation.

First developed for the US Navy at Johns Hopkins University in the late 1950s, satellite coverage became continuous for the first time from 1964 onwards. This was yet another instance of how applications developed for military purposes were eventually more widely adopted for non-military use. By 1970, satellite navigation was already in use on board the passenger ship *Queen Elizabeth 2*, the tanker *Manhattan* and the containership *Margaret Johnson*. Similarly, a decade later, the US Department of Defense began developing the Global Positioning System, today in almost universal use and commonly understood the world over by its initials, GPS. This complex technical system required more than two decades of research and development before it reached fruition in 1995. GPS, with more than 24 satellites orbiting the earth and broadcasting precisely timed signals to receivers calculating latitude, longitude and elevation to incredible accuracy, has rendered conventional navigation techniques and radar virtually redundant for determining a ship's position. But there was concern that the introduction of yet another discrete electronic system to the ship's bridge, run in parallel with several others, would increase the pressure on duty officers, especially at critical times during a voyage such as making landfall and navigating coastal waters.

As a way of overcoming this problem, work was already beginning on developing the concept of the integrated bridge, enabling centralised control over all onboard systems. Closed-circuit television cameras, remotely controlled from the bridge, were introduced to help navigation in confined spaces, and proved particularly advantageous for the bigger and longer tankers and bulk carriers built with their bridges aft. Early experience showed, however, that deficient design of onboard systems could create more problems, as witnessed in the grounding of a passenger vessel in 1995. The incident combined all the principal drawbacks stemming from the increased use of technology: over-reliance of officers on watch upon automated systems; inadequate training in automated systems; and poor design of the integrated bridge system. Other hazards included the weather, as a freak wave could hit the bridge and knock out all the electrical systems. The IMO set standards for integrated bridge systems in 1996, and specific safety requirements were incorporated within SOLAS in 2000.

The digital revolution was beginning to transform traditional concepts of navigational assistance. In the early 1990s, trials by the US Coast Guard demonstrated that electronic charts, or the Electronic Chart Display and Information System (ECDIS), were more reliable than the usual paper charts. The advantages of ECDIS were numerous, from supplying constantly updated information to displaying a ship's position in real time, as well as enabling a more accurate prediction of a ship's arrival in port. ECDIS supported the Automatic Identification System (AIS) being developed at the same time. An automatic tracking system designed to identify and locate vessels electronically by sharing data with other nearby ships, AIS information, which itself complemented marine radar, was supplied via ECDIS. No longer did seafarers have to collate and interpret information from several disparate sources; instead the electronic chart combined all this information for them, providing it in comprehensive graphic form. On the other hand, it was not infallible, and came with the risk of inaccurate chart data being used, or an incorrect position being determined. New problems have arisen with their use, particularly when users are trying to switch between various layers of information electronically: data can be switched off and forgotten, meaning users are not working with all of the available information, which has led to some collisions and groundings. Once again, the warning was that 'experienced mariners never totally rely upon any one system. For them, an electronic chart is another navigational aid with which to make informed decisions'.[2]

This has become a consensus, with the gradual recognition that digital technology is not foolproof and over-reliance on electronic systems is unsafe. So, to counter the possibility that satellite navigation systems might fail, terrestrial systems have been revived. For instance, an upgraded version of Loran C, known as e-Loran, has been pioneered in the UK, where several coastal transmission stations are now under development, supporting GPS as a complementary but independent system. Rolling out this system over wider areas worldwide will, however, take years to coordinate and complete.

There has also been increased stress on the importance of training crew members to understand and make proper use of technology at sea, and on ensuring that the crew can revert to more traditional methods of navigation if all else fails. One seafarer, describing a total bridge blackout during one voyage, the port of call lacking repair facilities and the rest of the voyage navigated using the magnetic compass, sextant, chronometer, land bearing and watch by the naked eye, remarked, 'I've never trusted blindly in electronics since'.[3]

## Flags and Signals

Flags and signals have been in use at sea since the seventeenth century when they were used by the Royal Navy to communicate tactics during battle. Frederick Marryat, who at the time, was a midshipman in the Royal Navy created the first general code for merchant vessels; which was based on the earlier flag and signalling system used in the Navy, which was devised by Sir Home Popham in 1799. Marryat's code, named *A Code of Signals for the Merchant Service*, was published in 1817.

The code contained flag signals for six sections, including a list of signal codes for English men-of-war, foreign men-of-war and English merchant vessels. The code allowed merchant ships to identify each other using their unique code, the forerunner of the call sign, and communicate messages to one another. Ships were also able to communicate with land-based signalling towers stationed around the coast. Marryat's Code was much simpler than previous naval signal systems, and became a great success in the merchant marine.

In 1855, the Board of Trade set up a committee to draft the *Commercial Code of Signals for All Nations*, which was adopted by most seafaring nations in 1857 and contained both British and international signals. The code was revised again in 1887.

The advent of radio and satellite communications resulted in a decrease in the use of flags and signals for communication, although the *International Code of Signals* is still produced by the International Maritime Organization (IMO) today, its last revision was in 2000, the IMO having taken over publication in 1965. Today the *International Code of Signals* uses seven different methods of signalling, including flag and light signalling and sound signalling, including Morse Code and radios.

### Semaphore

Semaphore is a means of communicating messages using a series of flag sequences, each representing a letter of the alphabet or number, to spell out words. It was developed by Claude and Ignace Chappe, who intended it to be used to communicate messages from telegraph stations using mechanical arms. Semaphore was used on ships to convey messages quickly when at close range and is still sometimes used between naval vessels.

### Light Signals

Light signals were used on ships at night when flags were not visible and were typically transmitted using a signal lamp. By 1867 a new system had been developed by Captain Philip Columb, which used long and short flashes of light; when Morse Code was later developed messages were transmitted using an Aldis lamp, a smaller hand held electric light. Morse Code messages can also be transmitted using whistles and foghorns in place of lamps.

Taking account of human behaviour at sea has been a driving force behind many of the reforms for improving safety at sea. There was also a growing appreciation that life on board should become more comfortable in order to continue to attract and retain crew. During the interwar slump, for instance, difficulties in recruiting engineers for the British mercantile marine led the IMarE to make proposals for improved pay and conditions to the UK Shipping Federation. These recommendations included extending privileges to engineering officers already given to deck officers, whose status was still considered superior. This was already changing, evident in vessels such as the motorship *Blackheath* commissioned by UK shipowner Watts, Watts & Co in 1936, which abolished the traditional segregation between engineering officers and deck officers, creating common dining and smoking rooms. The vessel reflected the changes made that year to the *Rules for Masters and Crew Spaces*, which stipulated a cabin for every officer and engineer; no more than three crew to a cabin; separate mess rooms adjacent to the galley; better insulation, heating and ventilation; adequate rat-proofing for all accommodation; facilities for washing and drying clothes; and shower baths for all departments. Once again war also precipitated changes, including better heating on ships operating in cold waters and the extension of air conditioning on board ships in tropical conditions.

The concept of human engineering had been taking shape prior to 1939. Sir Westcott Abell had defined as risks what he described as 'the "human" group [which] includes errors of judgement of masters, pilots, officers and crew, either through want of sea-room, bad look-out, neglect of rules of the road, lack of knowledge of seamanship, and bad loading or ballasting of the vessel, as well as overloading'. He linked these with weather risks in that casualties in both groups 'can only be prevented by better knowledge and education'.[4] After the war the concept was only slowly developed. In 1950, for instance, a doctor delivered to members of the INA a paper, 'Some Recent Studies of Human Stress from a Marine and Naval Viewpoint', dealing with the impact of temperature, noise and other environmental variables. As ships became more complex, and the consequences of flagging out became understood, LR initiated research into ergonomics and its application to ship control rooms in the 1960s. Yet in 1969 international action was still only being considered to improve training to reduce the incidence of accidents at sea. In 1972 the Convention on the International Regulations for Preventing Collisions at Sea, held in London, debated the need to reduce risks occurring through human error – the cause of most collisions – through further research into the human perception of the physical environment, the understanding of available information and an assessment of possible action.

As the cost of fuel rose after the early 1970s, there was a renewed search for economies, and the spotlight inevitably fell on crew costs as the other major component of voyage costs. Shipping companies began to concentrate on recruiting crew members from less developed and thus less expensive parts of the world, especially the Philippines. This was not a new development but increasingly widespread. The consequences only gradually became clear. By the mid-1990s, for example, the oil tanker fleet operated by Chevron employed crew members from 20 different countries. With so many different cultures and languages, teamwork, effective communication and an understanding of cultural diversity was critical for safe and efficient operation at sea. As well as reducing the cost of employing crew, shipping companies were also seeking ways of reducing overall crew numbers. Technology, in the form of increased automation, was the obvious option.

The failure to understand the risks of pursuing these developments independently was highlighted in numerous incidents even though these risks had already been identified. In 1984 one technology expert, Professor R V Thompson, had emphasised that 'crew minimisation and system reliability are interlinked. The first cannot be achieved without a significant improvement in the latter'.[5] In an era of new technologies, past sea-going experience was no longer relevant, while reduced manning levels were stretched by extreme circumstances. All this was understood by the classification societies, whose research explored not just new forms of automation but also how technology could refine the way crew carried out their work while reducing the scope for human error. Their work also covered the development of monitoring and the design of applications to help the crew make decisions.

LR's interest in this area emerged out of its Systems and Software Engineering Research Group from 1984 onwards. From the outset, this group appreciated that human factors were an integral part of assessing the safe and efficient operation of engineering software. The group also stressed the need to take the user into account when designing such systems in a new ship. The pioneering nature of this work may be gauged from the initial reluctance of LR's Marine Division to accept that human factors should be an essential part of its work. This was symptomatic of the tardiness of the industry as a whole to grasp and recognise the importance of human factors. The problems may have been well known for centuries but the difficulty for the industry lay in finding effective solutions.

LR pioneered the concept of 'total system dependability' in the marine sector through the Advanced Technology to Optimise Manpower On Board Ships (ATOMOS) series of projects. These demonstrated the value of integrated ship control systems and developed assurance for such systems to an international standard. In 1990, in collaboration with leading shipping companies and two other classification societies, LR was developing Quality Management Systems for shipping, recognising the importance of reliable management and sound operational practices to minimise the risk of human failure. By 1992, LR was carrying out research into the development of safety critical systems, smart structures (that is, the use of embedded sensors for system monitoring), and assessment procedures for fatigue performance. In 1994 LR was involved in a European Union ATOMOS research project, concentrating on integrated ship control systems. A decade later LR was developing Organisation Culture Diagnostics for shipping companies. One of LR's publications noted that 'Organisational weaknesses are viewed as barriers to safe, effective operations; therefore Lloyd's Register's risk team offers a structured set of recommendations to give the client a clear roadmap to tackle the areas that require development'.[6] Most recently, LR initiated a project studying the interaction between the technical and operational side of life on board and how this can be improved through the study of human factors.

A small group of highly talented people, including Clive Bright and Jonathan Earthy, were behind the development of this area; and Vaughan Pomeroy, who had long championed this topic within LR, ensured its future by transferring staff into an LR Marine Human Factors group. Confirmation of the importance of this work came in 2006 when LR's Technical Committee agreed that human factors should be integrated within the *Rules*. In 2007, LR launched the Human Element Gap Analysis, helping operators to review and improve their management of human factors by accepting that people were integral to the safety and efficiency of the ship. In 2008, LR also acquired the research consultancy Human Engineering, to expand its work in this field.

To raise awareness within the industry, from 2003 LR sponsored the Nautical Institute's International Maritime Human Element Bulletin, *Alert!*, and from 2007 began publishing *Human Focus*, covering human factors in ship operations. Today, LR's human factors teams consider the application of psychology, physiology, anthropometrics and biomechanics in design to enhance health, safety, usability, performance, and user experience, across a whole range of industries.

LR was not alone among the classification societies in developing understanding in this field. From ABS, for example, James Card, Clifford Baker, Kevin McSweeney and Denise McCafferty presented, in 2005, a paper 'Human Factors in Classification and Certification' to SNAME. In 2010 ClassNK published *Guidelines for the Prevention of Human Error aboard Ships through the Ergonomic Design of Marine Machinery Systems*. Similar work has been and continues to be carried out by the other major societies, including BV and DNV GL, illustrating the importance now attached to the subject. Today the International Association of Classification Societies (IACS) considers that 'the human element must be considered the most important contributing factor to safety and environmental protection'.[7] and furtherance of research in this area, and the implementation of any conclusions in an uncomplicated fashion, is part of IACS' current strategy.

Ironically, the development of systems to make running a ship safer and easier for smaller crews also reduced the level of responsibility they enjoyed. It was the latest step in a process that had begun with the introduction of cable communications and the wireless. At the same time the attractions of a life at sea were diminishing. This was the age of the container ship spending long periods at sea and very little time in port, usually docking at isolated terminals with little or no shore leave. Fears about absconding crew and the threat of terrorism often left many crew confined to their ship. It was not only recruitment that became a problem, but also retention.

Crew members may have needed higher skill levels to handle more complex operating systems, but then found themselves in mundane roles, their functions confined to navigation and catering. Their responsibility for cargo was much less important, especially on containerships, yet with larger ships often carrying more valuable cargoes any failures had greater consequences. Maintenance was often sub-contracted, divorcing the crew from an intimate understanding of the ship as a structure, and reducing the scope for feedback to highlight problems. Few crew members signed on for the long term, resulting in a falling proportion of experienced seafarers. This in itself was seen as increasing risk at sea, as one commentator, David Patraiko, observed in 2013:

> *'Over the years mariners have learned to adapt to ships and the sea. Any professional will be able to identify a "sixth sense" that allows them to detect a critical issue that they weren't aware they were looking for. Well-trained mariners with experience and a good attitude are almost unbeatable for assessing risk and making complex decisions.'*[8]

As John King noted in 2000, 'at a global level ships are elements of a world encompassing network that exists to facilitate international trade and commerce and takes everyone within its grasp; while at an individual level, the skills and experience of seamen have been rendered redundant, or subordinated to the world task'.[9]

The dangers in this situation, and how to tackle them, were publicised in *Alert!* The state of play was summed up in the issue for September 2007. Automation could turn an operator into a monitor, diminishing alertness and a feel for what is wrong. A chief engineer related how automated plant and machinery had turned engineers into monitors with little experience of manual control while the importance of the skills needed to manage if automation failed was too often ignored.

Appropriate design based on the needs of the user (or User Centred Design, as the concept was known) was as important as training and more accessible operating manuals, and should be an integral part of the overall design of any new vessel. It was essential for the shipping company to provide the shipbuilder with prescriptive specifications for automated systems and alarms, designed to ensure the operator remained engaged, alert and competent to make sound decisions. Once more it was emphasised that automation should not be seen just as a way of saving money. Reliability, it was stressed, would always be a concern with automated systems, and no system could ever replace the duties of the officer of the watch. Yet even today, for all the effort of international regulators and leading classification societies, these are lessons still to be universally accepted. The feasibility of the totally unmanned ship is still being investigated and, while possible in theory, could not at present be used for an entire voyage or in congested coastal waters.

## End Notes

[1] Admiral Sir John Cunningham in Spencer Jones, 'The Development of Navigation', *The Journal of Navigation*, 1:1 (1948) p9

[2] Horst Hecht et al, *The Electronic Chart. Functions, Potential and Limitations of a New Marine Navigation System* (Lemmer, Netherlands, 2002) p198

[3] Juan Manuel Lopes, 'All at Sea' *The Navigator*, 4, (Oct 2013) p3

[4] Sir Westcott Abell, *The Ship and her Work* (London, 1923) pp28–29

[5] R V Thompson, 'Future Aspects of Marine Technology, Guest Lecture, *LRTA* (Session 1984–1985) p11

[6] 'Understanding People – the Common Element', LR *Horizons*, 23 (March, 2008) p21

[7] *IACS Objectives, Strategy and Short-Term Plan, 2013–2014*, p2

[8] David Patraiko, 'Driverless Ships – Mariner Response', *Seaways* (July, 2013) p14

[9] John King, 'Technology and the Seafarer' *Journal of Maritime Research*, 1 (2000) p61

# 1945-2015

# 14 Regulation and technology

Technology continued to influence the regulation of shipping after 1945. This was achieved largely through the International Maritime Organization (IMO), a single international organisation that also helped to unite an increasingly fragmented worldwide shipping industry. While safety at sea remained of paramount importance, the IMO also became involved in two other issues of major concern. The first stemmed from the growing volume of oil carried in single voyages by larger tankers, leading to a string of serious pollution incidents. The second concerned the need to regulate ship emissions as a contribution towards the management of climate change. Both issues precipitated major regulatory changes with a consequential impact on the development of shipping. At the same time a parallel system of regulation emerged as Port State Control spread across the globe.

The first international maritime body was born out of the pre-war international SOLAS conferences. After 1945, ownership, shipbuilding and crews were divided across many nations, making a single international organisation essential for uniform standards of safety at sea. National flags, and even national ownership, came to have little meaning in shipping. In 1948 the UN Maritime Conference held in Geneva drafted a convention for the Inter-Governmental Maritime Consultative Organization (IMCO), whose prime purpose was, as stated in its motto, 'Safe, Secure and Efficient Shipping on Clean Oceans'. It was, however, ten years before the convention was adopted, following which the IMCO was established in London in 1959. IMCO was renamed the International Maritime Organization (IMO) in 1982.

Inevitably constrained by the need for consensus among its members, the IMO has nevertheless had a beneficial impact on maritime safety. On its formation, the IMCO took over the management of the first International Convention for the Prevention of Pollution of the Sea by Oil (OILPOL 54) through its Maritime Safety Committee, although this covered only operational discharges following tank cleaning. This was an increasingly important subject given the growing size of oil tankers carrying substantial individual loads of crude oil capable of inflicting severe environmental damage in the event of a casualty. One such disaster came when the LR classed *Torrey Canyon* struck rocks off the Isles of Scilly (UK) in 1967. This spurred the IMCO into action, leading to the International Convention for the Prevention of Pollution from Ships 1973 (MARPOL 73).

An example of national intervention in reaction to an incident which has always been problematic for an international industry to regulate followed the devastating effect of the *Exxon Valdez* oil spill off the coast of Alaska in 1989. This led to the introduction of the Oil Pollution Act in 1990 (OPA 90), when the US insisted that in future only double-hulled tankers would be permitted in its waters. This principle was adopted by the IMO in 1994, although a 30-year phasing-out period was conceded for existing tankers.

Other achievements included the second International Convention on Load Lines in 1966, which agreed to various modifications taking account of developments, particularly in ship size and ship specialisation, since the first conference in 1930. SOLAS conferences continued to be held, also reviewing previous decisions in the light of new technological and other developments. The 1948 SOLAS Convention set out minimum standards for radar and tightened up radio watch regulations, including a mandatory continuous 24-hour watch. The 1960 Convention adopted Very High Frequency (VHF) radio for watch-keeping, which eventually became compulsory for almost all shipping in 1981. In 1977, the IMCO initiated a standard marine navigational vocabulary for voluntary adoption, helping to overcome the confusion sometimes facing multi-national crews over terms used in English as the international language of the sea. Following the SOLAS Convention of 1974, which obliged signatories to set up search and rescue facilities in coastal waters, the IMCO adopted the International Convention on Maritime Search and Rescue (SAR) in 1979.

More recently, the IMO has been tackling the impact of the mercantile marine upon the marine environment. Since 1997 the IMO's Marine Environment Protection Committee has been engaged in the formulation of regulations to reduce emissions at sea as a means of mitigating climate change. Only in 2011 did the IMO reach agreement on mandatory measures to reduce emissions. Taking effect in 2013, these were a contributory factor in the search for cleaner energy among shipowners and shipbuilders. To assist in this search, the IMO had also adopted the Energy Efficiency Design Index in 2011, followed by measures to facilitate technical collaboration and technology transfer in 2013.

There has always been a degree of resistance to regulation from a naturally conservative and competitive industry. In the fragmented shipping world that came after 1945, enforcement was yet more difficult. Historian Richard Woodman observed that 'The vigour of the free market often sidestepped [regulation] to leave a legacy of unsafe ships, incompetent or underpaid crews, polluted seas and declining standards.'[1] So it was unsurprising that there should be long delays in reaching agreement on any particular changes among member states (of which today there are 170) and then in persuading sufficient national governments to adopt any agreed convention in order for it to become enforceable worldwide. The speed of technological change determined that this process had to change, and today the IMO operates a system of 'tacit acceptance', enabling amendments to take effect within an agreed timescale, usually 18 to 24 months, provided objections are not received from a third of member states involved, or from member states responsible in aggregate for more than half the world's merchant fleet. Even so, some nations have still been slow in implementing and enforcing ratified conventions. The classification societies, however, were in a position to work more quickly and the role of class as a support to the statutory regulator grew in importance.

Once again it was often major incidents or disasters that prompted change. The enquiry following the sinking of the ro-ro ferry *Princess Victoria* in the North Sea in 1953 with the loss of 133 lives bought several safety issues to the public's attention. The *Torrey Canyon* disaster in 1967 prompted the IMCO to take action to prevent further pollution. The agreed convention on pollution only took effect in 1983. The sinking of the ferry *Herald of Free Enterprise* in 1987 and subsequent criticism of management failures as a contributory cause, led the IMO to begin the process two years later that would eventually lead to the mandatory adoption of the International Management Code for the Safe Operation of Ships and for Pollution Prevention (the ISM Code) in 1998.

As the rate of accidents at sea began to increase, the IMO began considering the need for better training in the late 1960s, finally securing agreement in 1978 for moves to improve worldwide safety and training standards for mariners; countries representing 93 per cent of world tonnage signed up to the International Convention on Standards of Training, Certification, & Watchkeeping for Seafarers (STCW). However, partly because of difficulties arising out of the cultural diversity among signatories, something that was also evident among crews, the STCW Code was neither uniformly applied nor properly enforced, which led to it being rewritten in 1995.

In the meantime, despite the efforts of the IMO to prevent pollution at sea, there had already been further major oil spills. First came the grounding of the *Amoco Cadiz* on rocks off the coast of Brittany in 1978, causing terrible environmental damage. As a result, a number of flag states decided to initiate a parallel system of regulation. The Hague Memorandum had been due to come into effect in 1978 but was delayed by the *Amoco Cadiz* disaster that March. The resultant public and political outcry led to a more stringent Memorandum of Understanding (MoU) on Port State Control (PSC) adopted by 15 European countries meeting in Paris in 1982. Principally intended to harmonise port state control in order to eradicate sub-standard ships in their ports, each signatory agreed to inspect at least a quarter of all ships entering their ports every year. But importantly the scope of the MoU was also extended to cover maritime safety and pollution prevention. Next came the *Exxon Valdez* disaster in Prince William Sound, Alaska, in 1989, and the breaking in two of the *Erika* off the French coast in 1999. The response to these casualties was the insistence of the US and the European Union (EU) that they would accept only double-hulled tankers in their waters.

# A brief history of UK tonnage regulations

Initially, tonnage was based on the number of containers of wine, or tuns, a ship could carry, the term was taken from the French *tonneaux*. In Britain, France and Italy, the containers could hold between 240 to 252 gallons of wine. By the seventeenth century, the cargo carrying capacity of a vessel became known as tonnage and the measurement was standardised to 252 gallons, which was the equivalent weight of 2,240lbs.

From 1303, Edward I levied a tax on all goods imported to England by ship, and the ton was the measurement used to calculate the taxes. This was based on the calculation below (all measurements in feet):

$$\frac{\text{length x maximum beam x depth of hold (below main deck)}}{100}$$

An Act of King Henry VI dated 1422 decreed that keels that carry coals at Newcastle should be measured and marked. The Act was later extended to apply to vessels at other coaling ports. An Act passed in 1694 attempted to base the maximum deadweight of cargo that might be carried, upon the principal dimensions, but this was repealed.

From 1775, all vessels carrying coal 'at other ports of Great Britain' were legally obliged to measure their deadweight up to a mark on the ship, but this law was widely ignored to avoid taxation and harbour dues.

From 1773 a system of measurement often referred to as Builders' Old Measurement (BOM) was passed and incorporated into the Registry Act of 1786, which specified that every decked vessel of 15 tons and over must be measured, and registered, with the newly formed Registrar General of Shipping. The regulations of 1786 remained in use until 1835 and were believed to give a more accurate cargo capacity of the ship, as it measured the length between the stern and stem post at deck level:

$$\frac{(\text{length} - 3/5\ \text{beam})\ \text{beam} \times \frac{\text{beam}}{2}}{94}$$

This method of measuring tonnage resulted in ships being built that were narrower and deeper, making them unsafe. Consequently, an Admiralty tonnage measurement committee was appointed in 1821, but their investigation came to nothing.

A commission in 1833 decided that internal capacity should be the standard of measurement and in 1835 a new tonnage law was adopted that came into force from early 1836, becoming known as the New Measurement.

Between 1836 and 1854, a dual scheme operated. Ships predating 1836 would report two tonnages, old and new measurements, whereas vessels built after the law was passed would report a single tonnage measurement. When steamships became more common, it was necessary to amend the rule for measuring tonnage, as steamships carried engines and fuel, decreasing their cargo-carrying potential.

In the Merchant Shipping Act of 1854, Moorsom's Rule was adopted, named after Board of Trade Surveyor General for Tonnage, George Moorsom. The system included rules for measuring the internal spaces of a ship, meaning any fees charged would be in relation to their potential earning capacity. The gross tonnage included the internal space in the ship, less the space used for the crew and navigation. The net tonnage was the gross tonnage calculation less the machinery space, reflecting the potential earning capacity of the vessel.

The Merchant Shipping Act was updated in 1894, now requiring professional Board of Trade surveyors to certificate ships and ensure they met the rules, the Act was further updated in 1906.

In June 1969, the International Maritime Organization (IMO) held the International Conference on the Tonnage Measurement of Ships, which adopted a set of universal measurements for tonnage. These regulations were put into effect on 18 July 1982, ships built before 1982 having until 1994 to comply.

The PSC concept began to spread as other ports became concerned that they would be seen as a safe haven for sub-standard ships. A series of agreements were reached during the 1990s, beginning with Latin America in 1992, and followed by Asia/Pacific in 1993, the Caribbean in 1996, the Indian Ocean in 1997 and the Mediterranean in 1998. With further agreements covering the Black Sea, the Gulf States, and West and South Africa, PSC now covers most of the world's shipping regions. Co-operation between the various PSC regions was intended to result in mutual acceptance of inspection results.

Following the implementation of the revised ISM Code in 2002, the various PSC authorities held concerted inspections, discovering a large number of breaches. This underlined the continuing need for co-ordination between owners, operators, flag state authorities and classification societies to ensure masters and crew were properly trained for the safe operation of the ship and the safe delivery of cargoes.

Given the huge scale of the challenges facing the industry, international regulation has often struggled to live up to expectations. While a single international organisation is necessary in an industry where national flags and national ownership play a much smaller role, the difficulty in producing a swift consensus on matters of concern sometimes results in action that lags behind technological and other developments. Moreover, long delays have been common not only in instigating action but also in agreeing and then implementing a way forward, while uniform enforcement has also proved to be difficult. By the late 1970s, the IMO had largely achieved its initial aim of formulating international treaties and other legislation concerning safety and marine pollution prevention. A number of important instruments have also been adopted in more recent years. One focus of the IMO is to keep legislation up to date and to ensure that it is ratified by as many countries as possible. Unanimity of this kind inevitably takes time. Nevertheless, IMO conventions now apply to more than 98 per cent of world merchant shipping tonnage. Currently the emphasis is on trying to ensure that these conventions and other treaties are properly implemented by the countries that have accepted them. The IMO is aware that a great deal more needs to be done to improve safety and prevent pollution; it is now concentrating on making sure that governments and the industry implement the measures that have been adopted more effectively.[2]

## End Notes

[1] Woodman, *The History of the Ship* (London, 1997) p315

[2] www. imo.org/About/Pages/FAQs.aspx – accessed 13/01/2015

1945-2015

# 15 The classification societies and the application of science and technology

The role of the classification societies changed with shipping itself after 1945. The fragmentation of the industry, combined with the pace of technical change, demanded greater collaboration between the societies in order to reach common agreement on international standards. As fragmentation made international regulation more important, so the leading classification societies became a vital component of this process. A more disparate industry became more reliant on the societies for technical guidance and advice, but the resulting commercial competition among them began to cloud their traditional role. This created a crisis of confidence, resolved as the societies worked out a more balanced approach to a changed situation. Collaboration with the industry as well as other partners was extended to research and development. The latter was now grounded in the scientific approach that had begun many years before and was increasingly assisted by advancing computer techniques as ship technology became more sophisticated. This also demanded a new approach to the development of *Rules*. Societies like LR covered a vast array of research topics, independently and in partnership. By the early years of the new century, LR was seeking deeper ties with research partners in order to keep up to date with changing technology.

There had been collaboration before the war with the seven leading classification societies meeting in Rome in their capacity as load line assigning authorities. In 1947, the LR Chairman, Sir Ronald Garrett, expressed the view that the societies should work towards a universal standard of classification, but this was a degree of cooperation that proved consistently elusive. The societies did, however, revive their meetings relating to load lines, convening next in Paris in 1955 and then in London in 1959. On the latter occasion, they agreed a common approach on load line assignment in advance of the International Load Line Revision Conference in 1961 (the Load Line Convention was adopted in 1966). The reciprocal agreements common amongst societies before 1939 had also encouraged greater communication between individual societies, and this trend strengthened after 1945. This was exemplified by the post-war revival of the Japanese society, Nippon Kaiji Kyokai (NKK), now known as ClassNK, which relied initially on the adoption of the *Rules* developed by ABS, the American society.

The rise of open registers, sometimes termed 'flags of convenience' since 1950 – in other words organisations that will register ships owned by foreign entities – accounted for 31 per cent of world shipping by gross tonnage by 1991. Panama had become the first open register in 1919, followed by Liberia in 1948. This was the beginning of a flurry of new flag registers, reaching a total of some 70 today, many of which, like Panama and Liberia, were ill-equipped in terms of their own knowledge, skills and resources to meet the challenges of classification. This brought the classification societies together as they strove to ensure that regulations and safety criteria were being properly maintained. The failure of the Panamanian Registry to observe and enforce the international conventions governing load lines and the safety of life at sea prompted discussions with LR, ABS and BV in 1949 that eventually rectified this omission. By 2009, the open registries of Panama, Liberia, and Marshall Islands accounted for almost 40 per cent of the entire world fleet in terms of deadweight tonnage.[1]

Technology also brought the societies together. During the 1950s tankers in particular were becoming bigger and bigger, stretching the existing steel specifications laid down by the individual societies. Many of these vessels were being built by the new Japanese shipyards, but ownership was spread worldwide and all the leading societies were involved in their classification. It was no longer possible for one society to set the standard and others to follow. But the inability to reach agreement on a common specification was a major concern for the shipyards. Sense prevailed. In June 1957 representatives of ABS, BV, DNV, GL, LR, NKK and RINA set up a joint working party and two years later at the Conference of Classification Societies, they adopted common specifications recommended by the working party, including standardising their requirements for steel in order to keep the range of grades to a minimum.

By then the IMCO (now IMO) had been formed, which from the start regarded the societies as indispensable for its purposes. At its first meeting, the IMO had considered the revision and unification of the rules governing tonnage measurement, calling on the assistance of LR technical staff. On the other hand, however, there was anxiety among the societies that the IMO might usurp their role, exacerbated because at the same time the involvement of the societies with the IMO was constrained since they could attend meetings only as part of their respective national delegations. In 1961, however, it was agreed that the IMO could involve recognised non-governmental organisations.

This encouraged the major societies to continue meeting regularly; several conferences were held in the early 1960s, and in New York in 1965, Hamburg in 1967 and Oslo in 1968. The societies broadened the scope of their discussions in recognition of the need for a more united approach to international classification. They were also conscious of the impact of a more fragmented, more international industry, as well as the accelerating pace of technological change.

For instance, the societies reached agreement on unified rules for ship steel, anchors and chain cables, and discussed common strength standards. The suggestion for a formal association was made at the Oslo meeting, and confirmed at another meeting in Hamburg in September 1968, when the International Association of Classification Societies (IACS) was founded. Shortly thereafter IACS was granted observer status by the IMO, cementing the relationship between the two bodies.

IACS became a forum for collaboration on issues of major concern arising from advancing technology. The most notable example of this came in the 1990s when the classification societies were under scrutiny following the loss of several large tankers and bulk carriers. In particular, following the *Exxon Valdez* and *Erika* disasters, and with the insistence of the US and the EU on double-hulled tankers, the major classification societies combined to produce a series of measures designed to minimise the impact of any future casualties. These included the unified regulations, embodying stronger inspection procedures, issued in 1993, and the *Common Structural Rules for Double Hull Oil Tankers* and *Common Structural Rules for Bulk Carriers (CSR),* published in 2006, to determine their construction and maintenance. All IACS members played a part in these, with LR, DNV and ABS taking responsibility for the *Rules* covering double-hulled oil tankers. The first double-hulled tanker built to the new *Rules* was the *Abu Dhabi Star* in 2008, classed by LR. In December 2013, IACS adopted the new rule set called the *Common Structural Rules for Bulk Carriers and Oil Tankers* (harmonised CSR).

As technological change was accelerating, business relationships were changing and business transactions were becoming more formal. No longer were contracts to build new ships held together by the personal relations between owners and builders. As many shipping companies began dismantling their own technical departments, shipowners and shipbuilders began to rely more and more upon the technical expertise of the societies. This began to change LR's approach. The Society's traditional attitude had been, as Ross Belch, Managing Director of Clydeside shipbuilders Scott Lithgow, put it in the early 1970s, 'You design it, we will approve it'.[2] This attitude died out only slowly within LR; a request from a ferry owner in the late 1960s for LR to design an improved propeller was said to have caused the Society's Chief Engineer Surveyor to turn puce. Another society, DNV, was more receptive, and the owner switched, never to return. Nevertheless, by the early 1970s Ross Belch was encouraged to see that LR was beginning to become involved with design at the outset. The societies, he said, were the independent arbiter between owners and builders. From the same period A Schiff, an engine builder from MAN Diesel, observed how the societies guaranteed a global standard of quality, 'their worldwide practical experience having a beneficial effect everywhere in rendering assistance in technical development'.[3]

The societies responded to calls for advice from owners and builders by branching out into consultancy work, which became an important part of their marine activities. Based on its investigative work into marine failures, LR's Technical Investigation Department (TID) became heavily involved in design evaluation, redesign and advisory work for owners. LR's plan approval centres located at the major shipbuilding centres around the world gave comment on how a design might be made more acceptable. But the downside of this was increasing competition between societies as they became much more commercial. Moreover, as shipping became truly international and much more competitive, the societies came under growing pressure to lower their standards. This was obvious as early as the 1960s, when the LR Chairman Sir Kenneth Pelly recorded that, 'It is to my mind somewhat disturbing that there appears to be a form of competition arising between classification societies as to who can produce the lightest vessel'.[4]

As Gerhard Kurz, the President of the shipping arm of a major oil company, later recalled, 'their traditional role as the custodian of unquestionable standards had become seriously eroded and needed drastic corrective actions'.[5] This was underlined by the rising number of bulk carriers lost during the 1980s and early 1990s that triggered the concerted effort to improve matters, once again raising the spectre that the societies might be stripped of their role. The response was led by LR, ABS and DNV. They also did work that led to enhanced surveys and later to the common structural rules drawing up a series of measures to strengthen classification and raise safety standards at sea, which were adopted by all IACS members. As a result, owners were discouraged from moving from one society to another in an attempt to avoid making repairs, while owners failing to make repairs were subject to more immediate moves for suspension of class and could not complete a transfer of class. The societies also invested in more comprehensive design standards and structural analysis, and improved use of information technology, as well as setting more rigorous survey requirements including fatigue monitoring. Training for surveyors and engineers was also increased. Recognising the importance of the triangular relationship between themselves, owners and builders, the societies reaffirmed their role as conduits of support and advice on current statutory and regulatory requirements and specific port requirements. All this helped the leading societies to re-establish their reputation, making it possible for John Carlton, then LR's Global Head of Marine Technology, to state in 2009 that 'our political and commercial independence enable us to adopt a broad, long-term approach to research and innovation. We pursue some projects that underpin the advancement of our technical knowledge base. Other projects are targeted at satisfying the identified business needs of the different ship-type markets and the product lines that we offer to our marine stake-holders'.[6]

This was a restatement of the approach LR had begun to develop in the post-war period. During the 1950s, LR had opened a research laboratory in Crawley in Sussex. This was led by Dr Stanley Dorey, LR's Chief Engineer Surveyor from 1933 to 1956, whose distinction in the field of engineering science made him one of the few members of LR to have the distinction of becoming a Fellow of the Royal Society. A number of others have been elected Fellows of the Royal Academy of Engineering and other venerable societies. Dorey had formed the Engineering Investigations Department, which later became TID, in 1947 so that LR could learn from engineering and technical failures and use the research to enhance the *Rules*. Much of the early work done at the laboratory on subjects such as propeller shaft connections was done in collaboration with the British Ship Research Association. In 1964, when LR merged its related marine research arms into the newly formed Research & Technical Advisory Services Department (RATAS), the *Annual Report* remarked that RATAS 'will explore new ways in which the Society can contribute towards the industries represented by its clients'. RATAS, of which TID eventually became part, offered clients diagnosis and solutions, and was one of the blocks used by LR to build closer client relationships. RATAS and TID also fed back information on technical failures, not just on LR-classed ships, but on others as well, in order that the *Rules* could be enhanced accordingly. RATAS was led by Dr Simon Archer, a student of Westcott Abell, who had joined LR in 1936. He wrote research papers on many topics, including gearing problems in large ships and the causes of marine crankshaft failures, and would become President of the Institute of Marine Engineers, as have many other members of the LR staff over the years.

The work of Dorey and Archer, of the Crawley laboratory and RATAS, epitomised the more scientific and systematic approach taken by LR. It was an approach that evolved only gradually, however, since it was not easy either to find engineers with the appropriate backgrounds or to persuade colleagues with a practical approach to value their contributions.

Moreover, even in the late 1950s there were still pockets of scepticism within the British shipbuilding industry about the benefits of applied science. W F Stoot, commented in 1959 how 'shipbuilding is ... an incredibly old industry which has had scientific techniques imposed on it. The synthesis of the two, albeit inevitable, is not yet complete, for two reasons. The one is an incomplete state of knowledge and the other is mistrust. It would be of benefit to be rid of the latter'. Happily, other shipbuilders in other parts of the world took a more enlightened attitude.[7]

LR's approach could be traced back to pioneers within the Society such as Benjamin Martell, whose work had been continued by men like James Milton, James Montgomerie and Westcott Abell; while immediately after the war it was evident in the work done by Geoff Boyd, Tom Bunyan, John Murray and others. Eventually published in 1970, Boyd's work on brittle fracture arising from poor quality welding, material quality and poor design of structural details on wartime ships, which helped to inform the standards for better quality steel, still remains valid today. In the 1950s Bunyan worked on fatigue in propellers, devising a solution that involved shrinking the propeller sleeve onto the shaft, thus obviating the need for a key on the shaft, where cracks had been appearing. Bunyan would later remark that 'For most of a 20 year career at LR, trouble-shooting on ships was my meat and drink, so to speak. This experience gave me a unique opportunity of finding simple, practical solutions to some of the recurring problems.'[8] This was the Pilgrim Nut, designed and manufactured by Bunyan's own business, Pilgrim Engineering, a name designed to play on the relationship with his surname. The frictional grip of the Pilgrim Nut between propeller and shaft can be set in advance, and so it soon became the *de facto* industry standard for fitting propellers – quick, safe and cost-effective, the acme of technological ingenuity. In the 1960s John Murray, the Chief Ship Surveyor, researched the flaws and any damage affecting early container vessels, concentrating on changes in longitudinal strength and on modelling loads into the structure.

The work of the TID into vibration produced methods of locating, measuring and resolving vibration problems, especially propeller-induced issues. All this work, initially derived from empirical observation but carried out scientifically, not only helped the industry but also aided the Society in formulating and improving its *Rules*.

The basis for the *Rules* had become more and more scientific as engineering knowledge increased, much of the groundwork done by Stanley Dorey. For the first half of the twentieth century the Society had continued to take a relaxed view about revising the *Rules*, but this changed as bigger, faster and more specialised ships began to appear from the late 1950s onwards. This was accentuated by the demand for hull and machinery to be treated as an integrated whole, as technology made them increasingly interlinked. The traditional method of developing the *Rules* could no longer keep up with the pace of change, which also exposed limitations within existing classification *Rules*. As ships became larger, it became obvious that the only way to verify the scantlings for a containership or bulk carrier or tanker was by direct calculation from first principles. The *Rules* began to be looked upon not so much as a set of parameters as a complete system of analysis, requiring a return to basic concepts and the development of risk-based methodologies. The aim was to encourage designs of optimum strength through a more flexible approach which could encompass future developments as well as current practice. All this had to be achieved while pursuing the traditional aims of the *Rules,* that is, reflecting the accumulated data taken from the operation of existing vessels while taking into account future developments. In addition, they also had to embody the regulations and recommendations of organisations such as the IMO and IACS, which were another stimulus to change. For instance, IMO set standards and rules for interpretation by the classification societies, who were authorised to issue the necessary statutory certificates on behalf of the various flag states, particularly those without strong maritime expertise. Industry too sought change, wanting guidance in place before new technology was taken up.

# The Lloyd's Register Technical Association (LRTA)

The Lloyd's Register Technical Association (LRTA) was founded in 1920 as the Lloyd's Register Staff Association (LRSA) and renamed Lloyd's Register Technical Association in 1970. The objects of the LRTA were set out in the *Rules* at the first meeting held in the London office on 6 February 1920:

> *the object of the Association is the advancement of and dissemination of knowledge of present day problems in shipbuilding, marine engineering and aircraft. This object is pursued by the presentation and discussion of papers written by surveyors and other members of the staff in various ports.*

In his Presidential address in 1920, William Watt, a Senior Surveyor in London and later Principal Surveyor in charge of the Freeboard Department, hoped that every member of staff from the UK and abroad would contribute from their store of knowledge and experience to further the aims of the LRTA. Watt also said:

> *modern conditions in our offices as well as in our workshops and factories demand specialisation, and even in the prosaic atmosphere of Lloyd's Register, specialisation is becoming more and more the normal condition … We are all specialists more or less, and it is in the dissemination of this specialised knowledge that our Staff Association will find its most active and fruitful field of operation … In our outports and in the foreign field we have men who are acknowledged authorities on all questions relating to the practice of shipbuilding and engineering … with our meeting tonight we commence another chapter in the long and honourable history of LR, and I venture to think that in our Staff Association we will write a chapter which will hold its own with any that have gone before.*

By the mid-1990s, some 390 papers had been read at the Association, rising to well over 400 papers by 2000. The activities of the Association were suspended during the years 1939 to 1946 owing to the Second World War; the papers were written, but not formally presented to the Association. Today, papers are still presented in London, with colleagues around the world able to take part in discussions online.

The LRTA papers are extremely valuable in providing a distilled view of a subject written by an expert to be used by staff for self-development and reference. Initially only published for staff circulation, the papers are increasingly being made available to external audiences in the wider industry.

The LRTA attracts papers on a wide variety of subjects, reflecting the work of LR over its long history. In the 1930s, when LR appointed seven aircraft surveyors, several papers were presented on aircraft including a paper entitled 'Some Technical Aspects of the Commercial Airship' by Barnes Wallis, the aeronautical designer and engineer. The variety of papers is reflected in the first session of the LRSA where papers were presented on 'The Measurements of Exceedingly Large and Extremely Small Quantities', 'The Freeboard, Stability and Seaworthiness of Shelter Deck Steamers', 'Forging Practice', 'Recent Developments in Oil Ship Construction', 'Some Notes on Plating and Riveting', 'Trawling and Drifting', 'Internal Combustion Engines' and 'Floating Docks'. The trend in the variety of subjects has continued, with papers representing the breadth and sophistication of work being undertaken ranging from the inspection of nuclear installations, lifesaving appliances, and welding, to marine emissions.

Now 95 years old, the LRTA continues to fulfil the aims set out in its inaugural meeting in 1920. The dissemination of such information is regarded as even more important today when so much can change so quickly. The association is adapting constantly to the changing requirements of LR staff and has become an essential part of the way in which LR distributes information to employees all over the world.

LR, like every other society, made the most of advancing computer technology in tackling this task. Writing in 2010 on the impact of computing, Philip Christensen noted that 'the evolution from paper tape and punch card batch processing of stability calculations, through to the modern 3D, interactive modelling of entire ships, has empowered naval architects more than any other technology in naval architecture history'.[9]

For several years LR had the advantage over other societies in operating its own large mainframe computers. Early on LR was using NASA Structure Analysis, or NASTRAN, the commercial application of software developed for NASA, which LR was also permitted to modify for its own use. This helped LR to expand the application of Finite Element Analysis (FEA), breaking down complex structures into a mesh of tiny structural elements for computer analysis. This work had in fact been pioneered by ABS, which had collaborated with the oil company Chevron and the University of Arizona in the late 1960s to devise computerised techniques incorporating FEA that would be able to analyse as a whole the main hull structure and machinery of a new generation of giant oil tankers. The first design subject to this technique was for the 212,000 dwt *John A McCone* in 1969. FEA was subsequently applied to LNG carriers, containerships, bulk carriers and other large vessels. Only the use of advanced computer programs like FEA made possible the precise quantification of loading and the response of structures and the execution of stress analysis on a sophisticated theoretical basis. The techniques enabled alternative design configurations to be readily explored.

By the early 1970s LR was using computing extensively and devising its own dedicated software. Trends in defects and damage among classed shipping could be more rapidly and effectively assessed, initially using punch cards. Ship plans could be appraised more speedily and thoroughly. LR's integrated structural analysis and design system allowed the naval architect to build LR's philosophy into the design from the outset. Physical data collection did continue, and LR gradually developed a sophisticated and extensive technical database, representing operational data covering classed tonnage from 1960 onwards. This was a remarkable achievement, which could be utilised in the pursuit of more efficient ships. For instance, utilising historical data, LR was able to develop a model for calculating the optimum fleet characteristics for a particular trade, helping owners to avoid the expense of excess capacity. Shell, for instance, was able to remove one vessel from its fleet as surplus to requirements in the 1980s. Nevertheless, the trend was to move away from the collection of data and towards more computational work and analysis. In the 1990s, LR was among the first classification societies to apply Computational Fluid Dynamics (CFD) to ship design. CFD is a branch of fluid mechanics that uses algorithms to analyse and solve problems involving fluid flows. Its potential had been realised a decade earlier, particularly for the modelling of flow around a hull, and it was also applied to propeller design and the modelling of the combined hull and propeller. It could not have been adopted without computers, which made possible the complex calculations involved. LR quickly adopted the technique for advanced modelling; CFD helped to speed up the design process without incurring the time and expense of model tests or full-scale sea trials. The technique can be utilised to replicate a variety of scenarios. For instance, it has been used to model the spread of smoke in a passenger vessel and calculate the time needed for evacuation; to determine how best to minimise cavitation activity on a rudder's surface; and as an essential part of the design for LNG containment systems on large ships where operational data is lacking. CFD can also be combined with FEA to calculate structural loadings accurate enough to minimise safety margins.

Most recently, advanced computing methods such as CFD have been integrated within LR's Marine Technology Plan, which provides assurance for owners and builders working with new technologies and innovative engineering. On launching the plan in 2012, Tom Boardley, LR's Marine Director, once again underlined how intertwined the modern classification society has become with the industry: 'We are here to help the industry manage the changes we face by providing the independent insight that is required'. [10]

Today, computing plays an indispensable part in the classification society's principal role – the formulation of *Rules and Regulations for the Classification of Ships*. Hard copy and electronic *Rules* sit alongside one another. In addition to the published *Rules*, LR's Assessment of Risk Based Designs (ARBD) procedure was designed specifically for clients and surveyors working on projects for which prescriptive rules do not already exist or are insufficient. The procedure provides additional guidance in satisfying the requirements of classification *Rules* and statutory conventions when using risk-based techniques. This facilitates the development of designs that deviate from existing *Rules and Regulations*, including novel or complex designs. In this way, ARBD safely manages the implementation of new technologies, using the resulting experience to inform the development of new *Rules*. Societies like LR have covered a vast array of research topics. The British Shipbuilding Research Association and LR collaborated on measuring the response of actual structures in the 1940s, 1950s and 1960s utilising existing technologies. In the 1980s, LR's work on the behaviour of materials and engineering components covered:

> *the development and proving of innovative methods that allowed direct measurement of strain in dynamic situations in arduous conditions which few others could replicate at the time. The ability to measure gave LR the capability to make progress with developing the understanding of how engineering systems behaved in operation, discovering solutions to apparently intractable problems.* [11]

One aspect of this was the use of radio telemetry, using sensors on various parts of a ship's machinery from propellers to crankshafts, relaying information for rapid diagnosis on board, and in strain gauges on the hull. For example, in 1997, LR was working in partnership with a shipping company, BP Shipping, and a Korean shipbuilder, Samsung Heavy Industries, in carrying out a full-scale stress measurement project on an operating oil tanker, the *British Hunter*. Research was also conducted with the Krylov Institute in St Petersburg to test the behaviour of double-hulled structures on a large scale.

This was yet another example of the collaborative approach adopted from the 1970s. Research studies were becoming the norm for societies like LR, and ranged from projects that pushed the boundaries of existing knowledge to those that sought solutions for problems that would have been recognised by previous generations. For instance, in 2008 LR worked collaboratively with the operator, Qatar Gas Transport Company (Nakilat), the South Korean builders, Samsung Heavy Industries and Daewoo Shipbuilding and Marine Engineering Co. (DSME), and the multinational oil and gas corporation ExxonMobil, in a project to design a new generation of larger, more efficient LNG carriers, the *Q-Max* series with a capacity of 266,000 cubic metres. The result, reported LR's *Horizons* magazine, was that 'the mindsets that had dictated LNG designs for 40 years had been broken and the rule books torn up by a dedicated team of naval architects and engineers.' [12] Among other changes arising from this was a preference for slow-speed diesel engines over steam turbines, since the diesel engines were more efficient, used less fuel and were operated in conjunction with an onboard reliquefaction plant to reduce boil-off and retain as much of the original volume of gas as possible.

On the other hand, the first failure of a vessel built of traditional mild steel within the required specification and operating within approved parameters presented a challenge that might have seemed familiar to earlier LR personnel.

In 2002 the bulk carrier *Lake Carling* suffered a severe fracture in her side shell, resulting in the flooding of the cargo hold. Although she was saved, the Canadian authorities, in whose jurisdiction the incident occurred, demanded the substitution of a higher grade of steel with better resistance to cold temperatures than mild steel. This prompted resistance in the industry on cost grounds. Following work by LR within IACS, a compromise was achieved. By amending structural arrangements, it was possible to increase the use of steel more resistant to cold temperatures in the side shell of bulk carriers.

Similarly, when Mitsubishi Heavy Industries and Nippon Steel approached LR in 2005, they wanted to solve the tendency for the thicker steels used for bigger ships to be less resistant to crack propagation, that is, the inability for a crack to stop once initiated. Following this approach, the problem was taken up by IACS, initiating a project team to determine mitigating requirements that completed in 2012. At the same time LR worked with The Welding Institute (TWI) in the UK, which revealed that the problem had been known since the 1970s and came up with specific material testing methods. In 2013, LR introduced new *Rules* for thicker materials based on the results of the TWI research and new IACS unified requirements. Following further collaborative research with a major Korean steelmaker, LR adopted innovative testing methods for thicker steels in 2014.

For much of this period, LR's research was conducted independently, supported by dedicated research facilities, at Crawley until 1988, and then at Croydon until 2011. But the trend was for more and more research to be carried on in partnership. LR first entered into joint research and development projects in the early 1970s. With the decline of technical expertise within many shipping companies, these ventures soon involved partnership with both sides of industry. By the late 1980s LR was not only taking part in research funded by the European Union or the UK government, such as EU-funded research on software integrity and the UK government's Efficient Ship Programme; it was also sponsoring PhD research in several universities, such as Glasgow, Newcastle, Southampton, Gothenburg and Delft. Some of this work was done to assist the IMO. For instance, the IMO's first emission standards benefited from the work on measuring emissions carried out by LR in the early 1990s under John Carlton and Gill Reynolds; and the IMO makes routine use of the formal safety assessment methodology developed by LR in association with the UK Maritime and Coastguard Agency (MCA). Latterly, LR's work in energy conservation and emissions reduction has also included classing ships complying with IMO emission regulations.

By 2012, as the LR *Group Review* noted, LR was: 'focused on putting academic research, ship science practice and commercial expectations together and we are moving closer to a model that we hope will become more common.' This unified approach was encapsulated in the development of Joint Industry Projects (JIPs). These have become an invaluable part of the search for more efficient ways of operating ships at a time of high fuel prices and growing regulation of emissions. LR has worked with Maersk on the development of biofuels, and with the Chinese shipbuilder, Bestway Marine Engineering Design Company, on the design of more fuel-efficient bulk carriers.

The need to keep in touch with the latest technological developments encouraged LR to deepen its links with academic partners around the world. In Singapore, one of the world's leading ports, LR worked with the Agency for Science, Technology and Research (A*STAR) and others to develop a Global Technology Centre, which opened in 2013, with a focus on the offshore and on-land energy sector, supported by the Singapore Government. At the same time plans were advanced for a similar centre, concentrating on marine technology, located on the campus of Southampton University. LR had links with the university stretching back to the early 1970s, when LR had recruited the university's first ship science graduates.

While LR had developed strong relationships with clients, benefiting from the supply of empirical data, it wanted to strengthen its connections with bodies supplying new ideas in the marine and related sectors. The idea for a Global Technology Centre (GTC) first emerged in the early 2000s on the initiative of Vaughan Pomeroy, LR's Technical Director, backed by LR's Chairman, David Moorhouse, and in discussion with Professors Geraint Price and Ajit Shenoi. However a commercial arrangement could not be achieved until Professor Don Nutbeam, Vice-Chancellor of the University of Southampton, and Richard Sadler, the current CEO of Lloyd's Register, through their flexibility turned dream into reality and a mutually beneficial agreement.

The Southampton Marine and Maritime Institute (SMMI) took shape first, in partnership with LR and other organisations, focusing on materials engineering and ship science, and by 2014 it had more than 1,000 researchers, establishing a unique interdisciplinary centre of excellence. In 2006, in order to be closer to the university, with its strong reputation in engineering and applied science, LR began a phased relocation of all its London–Southampton marine operations and its London-based global marine specialists to Southampton, followed six years later by the metallurgical failure investigation laboratory. The intention was to open the new GTC, which would incorporate a towing tank funded by The University of Southampton, in 2015. As Vaughan Pomeroy remarked when the plans for the centre were announced, 'Lloyd's Register's prime concern is with technical issues and the effective use of technology and our research and development activities require the maintenance of regular contacts with people on technology issues'.[13]

By then the world of the major classification societies had been thoroughly shaken up by a rare merger that highlighted the internationalisation of the shipping industry. In 2013, the 13 leading classification societies who were members of IACS accounted for the classification of 90 per cent of the world's shipping. At the beginning of that year the three leading societies were ClassNK, ABS and LR. This was overturned at the end of the year by the exceptional merger between DNV and GL, which turned DNV GL, as it is now known, into the world's largest classification society. All of these societies, not least LR, see themselves as truly international, despite their national origins.

**End Notes**

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9 Philip Christensen, 'History of Computing in Naval Architecture', in *RINA 1860–2010* (London, 2010) p36

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13 *Ibid*, p35

1945-2015

# 16 The impact of shipping technology since 1945

Shipping technology has been indispensable in the acceleration of globalisation since 1945. Thanks to the modern ship, whether containership, bulk carrier or tanker, production is no longer confined by geography. Raw materials and manufactured goods can be shipped cheaply anywhere in the world. But the technology that has reduced the cost of transworld sea freight to historic lows has in turn made shipping, which carries more than 90 per cent of world trade, almost invisible, while removing for many officers and crew much of the initiative and enjoyment from the seafaring life. Ultimately, as ever, the wider adoption of ship technology depends on the commercial interests of the owner and operator.

The containership epitomises the impact ship technology has had upon the world. It stimulated the development of business networks and alliances, becoming the vehicle for the expansion of global markets. In its transformation from converted wartime cargo ships to the mammoth purpose-built vessels of today, the containership embodies the flexibility of the ship, its continuous technological development and the summation of the shipowner's eternal pursuit – economies of scale. Sea transport has the inherent advantage of low cost per ton-mile compared with other modes of transport of goods. The shipowner adopts the necessary technologies to make that possible and to continue with propulsion systems with low energy consumption per ton-mile, low manpower per ton-mile, and hulls with high payload/all-up weight ratio, which other forms of transport do not inherently possess. The shipowners' pursuit is to achieve these, with ships appropriate to the trade, more efficiently than their competitors. Author Marc Levinson and others have recently done justice to this remarkable concept. Levinson has described how the containership has been fundamental to a supply chain that can ship goods via land and sea more than 11,000 miles from a Malaysian factory to an Ohio warehouse in just 22 days, at a cost per container with 10–20 tons of cargo that is less than that of a single first-class air ticket. In 2014 the World Shipping Council stated that the cost of shipping a bicycle from Thailand to the UK by container was about $10. Similarly, a DVD/CD player would cost about $1.50 to ship by container from Asia to Europe or the USA while a kilogram of coffee would cost just 15 cents.

Writing in 2006, Levinson echoed the views more than a century earlier of Blue Funnel Line's Alfred Holt, the cargo ship king, observing that 'transportation has become so efficient that for many purposes, freight costs do not much affect economic decisions'.[1] Levinson contended that lower transport costs generated by the containership system helped international trade to increase faster than global manufacturing output or global economic output. 'Globalisation,' he continued, 'the diffusion of economic activity without regard for national boundaries, is the logical end of this process.'[2] This has the result of raising living standards in both producer and consumer countries.

It was an impact that extended beyond the containership. In fact, the containership joined a world-shaping line-up of ocean transportation, complementing the heavy hauliers of the oceans, the bulk carriers and tankers. The modern bulk carrier is also supremely efficient by comparison with its predecessors. With better machinery, larger, less resistant hulls, better propulsive efficiency and higher speed when compared to its predecessors of a century ago, it consumes in energy per ton-mile less than three per cent of what its equivalent did in the late nineteenth century. It was calculated that the average freights for coal and grain, two of the principal bulk trades, dropped by four-fifths between 1870 and 2000, with a ton of general cargo transported the 8,350 nautical miles from Rotterdam to Singapore in 2000 costing the same price as a ton sent the 2,060 nautical miles to Marseille in 1875. As one group of maritime historians concluded, there is no doubt that 'the growth of the post-war raw materials trade rested on a series of transformations and improvements in the existing seaborne transport system'.[3] The growth in trade was also accelerated by the switch of manufacturing to countries such as Japan, that have modest natural resources and so need to import much of their raw materials, in a similar way to that of Europe and the US during their period of industrial growth.

The refrigerated ship too belongs to this line-up, with the development of the first refrigerated bulk liquid tankers in the 1980s for the carriage of fruit juices. Moreover, in the words of one writer, 'anywhere in the world, or more exactly, in developed countries, anybody can taste strawberries in winter; seasons no longer exist thanks to refrigerated transport chains'.[4]

Together this modern fleet of specialist ships carries the raw materials that make the finished goods that are also transported by sea, while the maritime infrastructure supporting it makes it possible for consumers and producers to conduct business. By the early 1990s it could be stated with confidence by the author Gilman that 'modern shipping technologies of one form or another are now clearly a necessary precondition for economic development'.[5]

The cruise ship too is properly a phenomenon of the latter part of the twentieth century, in terms of providing leisure for more people more cheaply around the more exotic parts of the world. It would have been inconceivable to an earlier generation that cruising could become so affordable and so popular that today more than 14 million people take a cruise every year.

The twentieth century became the era of the bigger ship. Without an increase in ship size, it would have been impossible to sustain global economic growth. It was calculated that if a cargo ship's average size had remained at no more than 500 tons, as it was in the 1870s, one and a half million vessels would have been necessary in 2006 rather than the then 50,214 cargo ships in excess of 100 tons in the world mercantile marine. There would also have been a requirement for quaysides ten times greater in length than today's world tonnage. At the end of 2014, the number of cargo-carrying ships in the world fleet had risen to more than 55,000 with an aggregate gross tonnage of more than a billion.

Ironically, all this technology, representing the supreme achievement of the ship thus far, has tended to diminish the role of the seafarer. Recent writings about contemporary life at sea describe the boredom of those on board, despite more creature comforts aboard than their predecessors could have dreamt of. The crew often find themselves confined to their ships, rarely wishing to leave them as their giant vessels spend so little time moored at isolated terminals, one very much like another and even more devoid of local culture than the typical airport. In any case, some port states impose draconian conditions on crew, preventing them from leaving ship even if they wanted to. Pay rates and working conditions reflect the fact that crew costs remain one of the few areas with any flexibility for reduction, with low rates of pay for many crew members from the third world, and often a significant disparity in pay between officers, based upon their nationality and available skills.

Boredom comes in part from the fact that many modern ships almost run themselves. Crew and even officers have become systems monitors, the complexity of automated systems also denying them the ability to put things right when they go wrong. Moreover, remote monitoring is an increasing trend, with land-based staff in constant communication with the ship, their interference and lack of understanding of the vessel and the prevailing weather often frustrating long-serving, experienced seamen on board. During recent years fibre optic sensors have gained increasing interest in the field of ship monitoring. Fibre optic sensors have been used in a wide variety of applications, from monitoring machinery conditions to ship's hull strength monitoring.

The development of modern shipping, whether tanker, bulk carrier or containership, has also minimised the relationship of many people with the sea, unlike a century ago when many British families, for example, had a seafarer relative. Few realise that the modern consumer lifestyle of the world's developed nations relies on the sea and the ships which ply it, carrying more than 90 per cent of the world's trade.

# Dr Constance Tipper (1894–1995) and brittle fractures

In 1917 Sir Westcott Abell, LR's Chief Ship Surveyor led an LR research project into welding as a method of ship construction. LR carried out exhaustive tests and presented their findings to the LR Technical Committee resulting in the *Provisional Rules for Electrically Welded Vessels,* first published in 1918. LR classed the first fully welded ocean-going ship, *Fullagar,* in 1920, which was built at Cammell Laird and Company in Birkenhead. Between the wars, more shipyards adopted welding in their ship construction.

It is estimated by the United States Maritime Commission that over 2,700 ships were built across 18 shipyards over the United States during the Second World War to replace merchant shipping lost to enemy action. Welding was used for the construction of these ships, as it was quicker and cheaper than riveting and it took less time to train welders than riveters.

Many wartime standard ships averaged 42 days in build time; the California Shipbuilding Corporation completed 23 ships in December 1943. There was little control applied to welding, which resulted in inconsistent weld quality. In addition the need to X-ray each weld was not practised by all of the yards.

In total, over 20 per cent of the Liberty ships suffered fractures. One of the worst, the *Schenectady* cracked across her deck and both sides while berthed at the shipyard after having completed her sea trials just a few days before. Another, the tanker *Esso Manhattan*, broke in half in a calm sea shortly after leaving New York in March 1943. It was initially believed she had hit a mine, but further tests revealed her hull had fractured and split in half. Reports from the Captain and crew noted a sudden shock and vibration through the ship, as though from an explosion underneath. She was towed back to Brooklyn, her two sections were re-joined and three months later, she was back in service.

These events caused great concern on both sides of the Atlantic. The American Board of Investigation and the Admiralty Welding Sub-Committee were set up to establish causes and find a remedy to the problem. Initially it was believed that the problem in the ships lay in the welding rather than the steel. The Admiralty Welding Committee appointed a number of experts in the field including LR's Dr James Montgomerie, then Chief Ship Surveyor, and Rex Shepheard, Montgomerie's eventual successor. Both men had experience of welding on ships during their time in America. LR's Frederick Cocks, Special Surveyor for Welding, was also appointed to the Admiralty Welding Sub-Committee.

The Committee's Professor John Fleetwood Baker, Head of the Engineering Department of Cambridge University, appointed Dr Constance Tipper to carry out metallurgic, investigations into the steel used. After graduating, she had worked at the Metallurgical Department of the National Physical Laboratory in Teddington, as well as the Royal School of Mines in Kensington. Tipper's investigations showed that fractures occurred when the steel was subject to cold temperatures and that notches in the steel structure encouraged fracture, for instance at the corners of hatches. The steels used in ship construction became brittle at operating temperatures which increased the risk of fracture initiation at points of stress concentration within the structure including welding defects. The process of welding the plates together also revealed weaknesses in the steel that were not apparent when the plates were riveted. Once the welded hull started to fracture there was nothing to stop the fracture from spreading around the hull as the welded hull effectively became a continuous plate, whereas a riveted plate would isolate the fracture.

Tipper's research resulted in manufacturers improving the quality of the steel used, moving the temperatures at which brittleness developed to a much lower temperatures. After retiring Tipper continued to work as a consultant in Barrow shipyards, as well as supervising metal bridge construction. She gave have her name to the 'Tipper Test' used to measure this form of brittleness in steel.

The UK, for instance, depends on the sea for 40 per cent of all its food, and relies upon ships to meet more of its energy needs. China could not have become the world's economic powerhouse without the sea, which carries 90 per cent of the country's exports around the rest of the world. But the days are gone when commuters walking to work from London's riverside railway stations passed by the wharves and warehouses, teeming with dockers and other port workers, taking in cargoes from ships that seemed almost within touching distance. Today's major terminals, super-efficient, designed with economies of scale in mind, dominated by machines rather than personnel, handling vast volumes of goods from fewer, bigger ships, are out of sight, miles downstream from the cities to which they are notionally linked. The relationship has shifted. The regulations covering emissions at sea reflect that change, as the link has moved away from trade and employment towards ecology and conservation. There have been calls to impress upon the public at the same time that sea-borne transport in terms of carbon dioxide emissions is one of the least damaging, the world's mercantile marine accounting for between just three to four per cent of total emissions.

The modern ship is the most efficient form of mass haulage on the planet. As it has helped to accelerate globalisation, so it has transcended national considerations, as historian Alan Jamieson pointed out, 'today whether a ship provides a swift and cheap transport service is all that matters in this most globalised of industries; nationalist concerns are irrelevant'.[6] It is the product of constant technological invention, innovation and improvement borne out of the scientific development of naval architecture that owes so much to the great pioneers of the past, above all William Froude. Ultimately, however, it is always the international competition and bottom line that counts in driving innovation and improvement, considerations of revenue, cost and profit, as well as technology, finance and regulation. This has been evident in the last few years when slower growth, overcapacity, weaker freight rates and more demanding regulation have stimulated the search by owners and builders for new fuels, lower fuel consumption and more efficient operation. 'In the last resort,' wrote Martin Stopford, 'the ship in which a cargo travels is likely to be determined by commercial performance rather than its specific technical design characteristics'.[7] Or, as one industry journal put it, ultimately 'the technical specification of a new ship is tailored to an owner's expectations of the market in which they intend to operate'.[8]

**End Notes**

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[4] Jacques Mercadon, 'Conventional Cargo Liners and Refrigerated Ships', in Alistair Couper (ed.), *The Shipping Revolution: The Modern Merchant Ship* (London, 1992) p33

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# 17 The future

Evolution rather than revolution seems to be the prediction for the near future. Commercial and regulatory pressures are making ships more energy-efficient through better design, cleaner fuels, improved propulsion and lighter materials. Within the constraints of commerce and regulation, and the ability of ports to support them, it may be that ships will continue to grow in size, albeit much more slowly than before. Alternatively, diseconomies of scale may begin to affect other ship types, as has already been the case with tankers. The complexity of modern ship systems, and the failure to create common standards, has taxed the ability of crews to manage them, making full automation increasingly attractive. The sophisticated analysis of the deluge of data from more extensive satellite systems has the potential to further reduce operating costs, while swinging the development of ship technology away from the predominant scientific approach towards a sophisticated empiricism. Many of these changes will bring significant benefits only in the aggregate, although nevertheless worthwhile in terms of the overall operating costs of a major shipowner. To keep up with the pace of change, make the most of technological advances, and marshal the resources required for modern-day research and development, collaboration across all parties in the industry has become essential. The classification society itself will continue to have an important place in the industry in its traditional sphere as the guarantor of technical standards at sea, as long as it embraces the changes inherent in 'Big Data'. It also has a valuable role to play in helping the industry minimise the risks arising from the rapid adoption of new technologies while using those technologies to create a more sustainable form of ship. Whenever the next technological revolution occurs, the classification society will still be there to help it happen.

The consensus is that the main drivers of change in the immediate future will be commercial and regulatory. One of the lessons of the past is that technological progress is no good unless it is allied to profitable management of shipping operations. But some ships have achieved a maturity of technology, so while there will be detailed improvements, the basic concept will remain unchanged, as with oil tankers and bulk carriers. Currently profitability in the container trades in particular has proved elusive, leading even the largest operators to seek alliances in the search for further economies.

There would appear to be few technical constraints on how big ships might grow, as owners never relent in their search for cost savings, provided that sufficient cargo is available and that ports and terminals can supply the necessary supporting infrastructure. Even today the largest China-Max bulk carriers are in excess of 350 metres long, while the new generation of cruise ships being built for Royal Caribbean will be more than 225,000 gt and carry 5,400 passengers plus crew. The largest vessel constructed in 2014 was the *Pioneering Spirit*, a massive twin-hulled crane vessel, 382 metres in length and 117 metres wide, which was built to LR class for use in the offshore sector.

Ships will become more energy-efficient as the search for alternative fuels, and the provision of supporting infrastructure, continues. One major container operator, Seaspan, owning vessels that can carry up to 13,100 teu, is typical of the industry in opting for new ships that can operate efficiently at variable speeds. Seaspan has been promoting the advantages of slow steaming since 2006, but at the height of the trade boom charterers were not interested since the capital cost of tying up cargo at sea was unacceptable to shippers. With the slow-down of world trade, however, and rising fuel bills, average service speeds have come down.

For owners and operators, the benefits of alternative low flashpoint fuels, such as LNG, are their cleanliness, compliance with regulations and, currently, price advantage over marine diesel oil. LNG is not the cleanest alternative, as it still emits carbon dioxide and there are worries over the possibility of bunkering spills. As the largest constituent of natural gas is methane, there are also concerns over the impact on emissions of 'methane slip', that is, where the methane that is not used as a fuel in the engine escapes into the atmosphere. Nevertheless, LNG has become the accepted short-term alternative. Once again the process has been evolutionary, and the technology will still require the development of supporting infrastructure, in this case a network of fuel-bunkering facilities in major ports, before it gains wider acceptance. The prospects for this are promising, yet it is estimated that LNG will account for just 11 per cent of all fuel used at sea by 2030. While LNG is predicted to make up just under a third of the fuel mix of chemical/product tankers by then, in containerships it will account for just 5 per cent, scarcely a revolution in fuel use. It may be best suited as an alternative for coastal trades and specific parts of the world where local regulations require lower emissions and ports are therefore equipped with energy supplies. There may also be the possibility of devising an effective on-board carbon capture system to improve the environmental benefits of using the fuel.

Research is being conducted into a wide range of alternative supplies and into systems for making more efficient use of energy. Possible future alternatives include biofuels, hydrogen derivatives, new electric storage devices and fuel cells. Cheap electrical storage systems would be a major catalyst to change. Some still see a future for nuclear power, but politics, safety, the substantial cost of paying for fuel in advance and infrastructure implications make this only a very long-term possibility. Photo-voltaic (PV) cells have been installed on a car carrier, and flexible PV cells have been developed which could be applied to sails and used as an auxiliary energy source.

Opportunities exist for hybrid propulsion systems, such as diesel–electric systems, with batteries storing surplus energy for use at peak times. A further benefit could be a reduction in the size or number of generators, thus reducing capital costs. But the energy currently consumed in storing energy and later extracting it from storage makes such a system less efficient than a direct-drive diesel engine operating at constant speeds. There have been numerous experiments with the use of batteries to power ships. Two ferries operated by the Scottish operator CalMac Ferries Limited, the *Hallaig* and the *Lochinvar*, employ a hybrid diesel–battery propulsion system, using lithium-ion batteries. One of the challenges is developing a battery with a weight and cost that do not outweigh its other advantages.

The idea of reducing weight in order to reduce fuel consumption has led to the consideration of lighter construction materials, such as high-strength steels, aluminium alloys and fibre-reinforced plastic materials. Other types of steel are also being developed, such as crack-resistant and corrosion-resistant, as are other materials, such as the thin polycarbonates used for ancillary purposes on cruise ships.
At the same time, the pursuit of lower costs has led to a search for cheaper sources of materials, leading societies like LR to devise more stringent material inspections to assure the quality of the material being produced.

The cleanest and most abundant alternative fuel is hydrogen. There have been experiments with hydrogen-powered fuel cells creating surplus heat and water for recycling, and CalMac has developed a hydrogen ferry concept. But hydrogen requires massive storage, lacks worldwide availability, and has significant safety implications. Any calculation of its overall efficiency would also need to take into account the significant energy needed to produce and liquefy the gas. Liquefying hydrogen is, however, not the only option; hydrogen-bearing derivatives may be easier to handle and another possible fuel solution for the future.

Old technologies have been dusted down and reviewed. Research is being conducted into technologically advanced forms of wind propulsion, using sail as a means of auxiliary power. This would mean a reversion to the practice of devising routes that took most advantage of the prevailing winds, but longer routes may negate any gains in efficiency. Sails, solid and automated, have been proposed for smaller tankers, which would require retraining for crews. Before the First World War, the German naval engineers Knoller and Betz wrote papers on the use of flapping foils. Maximising wave motion to provide additional speed, foils have been developed typically for use on catamarans. Unintended consequences are a hazard of new technologies, as the early pioneers discovered, and flapping foils have been criticised for creating excess wash. Ways have been devised to mitigate this disadvantage, notably at the University of Southampton under Professor Philip Wilson, and applied in practice to two fast catamaran launches operated by the Port of London Authority on the River Thames, creating a less environmentally damaging and safer low wash. Another German engineer, Anton Flettner, devised the Flettner rotor in the 1920s, and this too has been revived, with the potential for making savings in propulsive power of as much as 15 per cent, although many in the industry are sceptical.

A more attractive alternative is the fuel cell, a tried and tested technology, reliable and easy to maintain. There have already been small-scale trials on ocean-going ships, using methanol as an interim fuel, and there are predictions that hydrogen fuel cells will ultimately replace combustion engines, especially since the 60–65 per cent efficiency of the former easily outstrips the 50 per cent efficiency of the latter.

# William Froude (1810–1879)

William Froude was an engineer and naval architect responsible for the extensive study of hydrodynamics on the hulls of ships. He was born on 28 November 1810 at Dartington Parsonage to Margaret and Robert Froude, the Archdeacon of Totnes. Froude was educated at Westminster School and Oriel College, Oxford, where he graduated in 1832 with a first in Mathematics. He continued to study, and was awarded his MA in 1837. Froude was tutored by his elder brother Hurrell, John Henry Newman and Isambard Kingdom Brunel, who he described as the 'greatest influences on his life'. In 1839, Froude married Catherine Holdsworth.

Froude worked as a studying surveyor under Henry Palmer, an engineer for the South Eastern Railway. In 1837 Brunel made him responsible for the building of a small section of the Bristol and Exeter Railway. During this time, Froude worked on the design of bridges and studied steam engines, until he retired in 1846 to care for his father.

His greatest work in this period was the study of hydrodynamics – the impact of friction on an object moving through water. Following further research, in 1861, Froude submitted a paper entitled 'The Rolling of Ships' to the Institution of Naval Architects, which was considered the first correct theory on the hydrodynamic behaviour of a ship at sea. Froude's theory was developed over the next decade and is said to have formed the basis of improvements in hull design. The Admiralty followed his research, which influenced the design of many warships. Froude was elected a Fellow of the Royal Society in 1870.

The previous year, Froude had worked with the British Association Committee to improve the approximations of powering a ship. The Association had initially insisted on a full-scale trial, but Froude persuaded them to test two different types of ship model, in the form of the *Swan* and *Raven*. The tests proved there was no optimum form for hull design, as had been previously thought, and both models performed better at different speeds. This meant it should be possible to calculate ship resistance from models' tests, this became known as Froude's Law, which is still in use today.

To test the theory further, a trial was arranged in 1871, when HMS *Greyhound* was towed at a range of different speeds while her resistance was tested. Sir Edward Reed, Chief Constructor of the Navy, persuaded the Admiralty to build a 278 foot tank, 38 feet wide and 10 feet deep, near Froude's house in Torquay. It was from this tank that Froude would obtain data on frictional resistance, leading to his construction of a dynamometer in 1873. The tank was in constant service until 1938, when it was decommissioned. Froude was awarded the gold medal of the Royal Society in 1876, for his work on hydrodynamics.

Two years later, in 1878, Froude's wife Catherine died. Froude was distressed and his friends and family convinced him to holiday in South Africa. Unfortunately, this would prove fatal, as Froude contracted dysentery in Simonstown and died.

With the development of electro-technology, automation will remain central to the operation of ships. But, unlike within elements of the aviation industry, systems and software harmonisation is a cost that the shipping industry cannot easily afford or implement. This has effectively left every new ship equipped with software and systems engineered for its own particular requirements. Thus, if a ship is operating without incident, the engineer is redundant; yet if a problem arises, the engineer can do little to help, lacking the intimate day-to-day working experience of such complex and multifarious operating systems. This encapsulates the problems of manning, training and accessibility of systems within the industry, which automation has sought to alleviate.

All this has made the autonomous pre-programmed algorithm-controlled ship an attractive proposition: it is expected that the next stage on this path, the semi-autonomous ship, will be sailing the seas within a decade. Such a vessel would remove the need for anything other than a fall-back crew on board, not only making savings but in theory creating a safer ship. It might even be possible to fly small drones ahead of the ship to monitor and relay information about sea conditions. Most of the technology is already available and the systems are proven, robust and reliable. The relatively slow speed of modern ships also makes it possible to relay information regularly by satellite to remote control centres. Some experts suggest that the completely crewless ship, perhaps only using a pilot on approach to port, will be a reality within two decades. However, the situation will be quite different for deep sea and in congested areas like the English Channel and the Malacca Straits, and coastal states would have to agree the latter operations, even though advancing technologies may well enable this type of operation.

One of the factors making this possible is the dissemination of abundant data by satellite from 2015 onwards, which will make it more practical to conduct remote monitoring of ships in real time. It will also strengthen the relationship between owner, builder and regulator, as data accumulates through the life of a ship, leading to a more integrated approach. The vast array of data, swiftly analysed by computer in an almost infinite number of ways, may also lead away from the scientific approach prevalent since the days of Froude towards a much more sophisticated empirical approach; it will certainly help naval architects and shipbuilders to devise ever more efficient designs and manufacturing processes. Manufacturers will no longer relinquish responsibility for the vessel on handover, but once the ship is at sea they will continue to monitor remotely the systems they have installed, all the time collecting more and more data, something that aircraft and engine manufacturers already do. This in turn can be used to feed into systems such as Smart Ship Design, which incorporates in the design and manufacturing process factors such as ease of handling and fuel, and crew and maintenance costs, with the ultimate aim of minimising overall operating costs. Major operators, too, will devise their own forward programme for reducing costs, and expect the shipbuilder, engine designer and component manufacturer to integrate such plans into their designs. In recent years this has led to a new phenomenon, with issues over patent rights; engine makers, for instance, are developing patents to cover new engines whose design is driven by international regulations. One of the mottos adopted by Samsung Heavy Industries declares, 'No patent, no future!'

In designing the most efficient hull, today's naval architect remains as constrained as his or her predecessors by external considerations such as length of berth and depth of water in the ports destined to be used by any new vessel. But once again improvements at the margins, such as more sophisticated air-water friction systems or bulbous bows, can contribute towards improved efficiency.

The concept of the driverless ship, removing the need for much of the accommodation superstructure in the absence of a crew, may have a radical impact on design. This, in combination with research into areas such as fracture mechanics, structural strength and new materials, hints at the potential of a revolutionary leap forward, although when and how this might be achieved remains speculative.

Even the largest shipping companies find difficulty in funding major research programmes on their own, especially since the rate of change is so rapid. Complex and expensive, the development of new technologies makes collaboration between all the parties concerned, from the owner, shipbuilder and marine engine manufacturer to the classification society and other bodies of learning, essential for the future of ship design and construction. Conversely, however, the commercial nature of these partnerships has had an adverse impact on the wider dissemination of information. Published papers too often demonstrate the capability and expertise of the research body involved rather than providing practical enlightenment for the external reader, with the knowledge embedded in software not accessible to others.

The quickening tempo of technological change has given the major classification societies the chance to cement their place at the heart of the shipping industry. The knowledge and expertise of leading societies like LR enables them to continue to assist owners, builders and others with the implementation of new technologies. While working together through bodies like IACS they will maintain their role in formulating the common international standards that seem more and more likely to be the guarantee for the safe and reliable working of these technologies.

As research opportunities multiply, the societies, whose own resources must also be husbanded, need to learn how to prioritise research, investing in areas of strategic importance while allowing themselves enough leeway to take up exciting opportunities as they arise. This makes cooperative working fundamental to the way the modern society operates. While the societies compete with each other in developing and marketing their own software and there is little sharing of knowledge, they do come together within IACS, and in various ad hoc research groups, such as the Cooperative Research Ships (CRS) group, which includes LR, DNV GL, BV and ABS sharing costs and research. One of the great strengths of such groups is the ability for work to be peer-reviewed. This also applies to initiatives pursued by societies individually, such as Joint Industry Projects (JIPs), an important testing ground for new ideas and developing common approaches to problems. JIPs are an important avenue for LR, as is the new Southampton Global Technology Centre (GTC). There is an expectation that this will create an exciting and stimulating collaborative partnership that will enable those involved to develop their understanding of the theory and commercial application of science and engineering. It will spark creativity, make things happen, develop new ideas for the future, attract outside interest, and develop into one of the few international resource centres for the marine industry. With the support of LR, researchers will have the confidence and resources to develop innovative ideas, drawing on LR's links with the industry to test them out in the field. This will test LR too, demanding a change of mindset on the part of LR surveyors and engineers, more used to concentrating on the more routine stage of technological development. The interchange of ideas and people will enhance LR's knowledge, contributing to new *Rules*, procedures and guidance, and ultimately to the better design, construction and operation of ships. Above all, the GTC aims to have a beneficial impact on the world of shipping, helping to create a safer, more environmentally friendly, more efficient industry, with benefits too for seafarers and their families.

The societies will continue to work towards securing more efficient ships. LR's own internal technical groups carry out research that leads directly to improvements in the *Rules*. LR also has a Strategic Research Group, under Fai Cheng, which leads the way in assessing how today's inventive thinking may turn into tomorrow's emerging technology. In addition, LR staff still prepare research papers and attend major conferences, partly as a means of promoting LR's technical capability in a competitive market, but also to disseminate information more widely.

An indispensable part of the sophisticated analysis involved is advanced computing technology. LR's Structural Analysis and Hydrodynamics Team is working on software to model and assess the impact of whipping and springing on ever larger containerships. It enables the wider application of techniques such as CFD and FEA.

LR has used CFD to recommend the optimum energy-efficient trim and draught, as well as using the technology to model air flow and assess the wind drag specific to vessels. The test findings allow estimated reduced fuel costs (dependent upon the particular conditions) of between 2.5 and 8 per cent. LR has also used FEA to assess the optimum relationship between rationalised scantlings and safety requirements.

Computing also makes it possible to include within the ship design process much more data reflecting the range of operations and sea states for any particular vessel, while enabling a more sophisticated approach to such studies. It is also facilitating a degree of integration between previously distinct technical areas, such as sea-keeping, manoeuvring and structural dynamics. An alternative to CFD currently being developed is smoothed-particle hydrodynamics, or SPH, which may yield similar advantages.

One of the challenges facing the leading classification societies is the forthcoming avalanche of data, commonly called 'Big Data', which in combination with massive computing power will make more certain predictions of future behaviour and performance in ships. Data analysis becomes much more important, making data analysis organisations the societies' rivals, and will have a greater effect on the way the societies operate than almost any other change since they first began. There will be fewer physical inspections of assets, the incidence of which in future will be predicted by an analysis of targeted data patterns. For the first time, data analysis becomes a fundamental skill within the societies. They must emulate existing well-established major data analysis organisations, and become stewards of more and better data collected on behalf of clients, guaranteeing their security in exchange for using them anonymously and in aggregate for the benefit of all clients.

The three principal drivers behind future ship technology remain the regulation of risk, the regulated protection of the environment and commercial considerations. There are many commentators who believe that regulation, by compelling operators and builders to change, has had a beneficial impact on the efficiency of the industry. But the weaknesses of the existing regulatory regime are likely to lead to further regulation. The industry still faces challenges that are likely to be alleviated only by more uniform enforcement of regulation. Emission regulations are seen by some as too weak, the burden always being passed on to the next generation of ships and failing to take into account the impact of an overall increase in trade. The entire mercantile marine may only account for 4 per cent of world emissions, but this is still larger than all those from Germany. As climate change makes possible an Arctic trading route and the exploitation of its mineral resources, further environmental damage can be prevented only through regulation. In November 2014, the IMO adopted the *International Code for Ships Operating in Polar Waters* (*Polar Code*) along with related amendments to the SOLAS convention to make it mandatory and cover the safety requirements of vessels operating in Arctic waters.

Inconsistent enforcement of international conventions remains a problem, and the emergence of Port State Control (PSC), while undoubtedly helping to raise standards on board many ships and within many open registries, has in doing so effectively squeezed out the world's worst shipping and left it beyond regulation in remote areas.

The rapid pace of technological change brings its own risks. Naval architects brought up on easy access to sophisticated FEA and CFD software programs can too easily ignore the fundamental physics involved; while a rising generation of surveyors can lose the instinctive feel for assessing detailed designs that comes with experience, relying too heavily on computer programs and failing to take into account their limitations. The knowledge of the crew often lags behind the technology while digital controls raise questions over ship reliability, safety and security. One cautionary tale relating to reliability involved an engineer installing a software upgrade for his ship's engineering systems, which then refused to work. He resorted to reinstalling the whole system but when this too failed it left the ship effectively stranded for three months at significant cost. Another story highlighted the potential safety risks where new technology is adopted with ill-considered design, working procedures and risk assessment. A cross-Channel ferry relying entirely on satellite navigation and dispensing with paper charts had occasion to divert from its normal route, which caused it to strike a submerged object, causing considerable damage. The detail that would have been immediately obvious on a paper chart had been lost on a computer screen since the crew had dialled down the detail to reduce screen clutter. As for shore-based remote monitoring, the risk lies in the lack of understanding of how a ship performs at sea on the part of those engaged in monitoring, leading to poor decisions in adverse circumstances. Security risks range from the ability of pirates to track a vessel's exact location, through knowledge taken from the internet of their individual vessel number and routes, to the threat of hacking as satellites supplying cheap data proliferate. In many of these areas the classification society has a role to play. Since the purpose of class is assurance, they can, for instance, assure through audit the training standards and operational competence of remote monitors.

Sustainable shipping will be achieved by securing the optimum balance between risk, commercial pressures and environmental regulation, which in itself provides further opportunities for innovation. As long ago as 2009, LR had summed this up succinctly in its journal, *Horizons*, 'Sustainable ships are ships that have a long-term future that will meet future trading requirements, will burn less fuel, cost less to run and be safer to operate.'[1] In the short term, the most effective remedy relies not on revolutionary change but on more investment in the design of bigger, slower, more efficient ships, with less resistant hulls and improved propellers and rudders. Small efficiencies from all these areas will make a significant overall improvement, especially when set against the colossal sums paid out by some major operators every year in fuel bills; with Maersk, for instance, spending $6 billion on marine fuel every year, even a few per cent per annum adds up to a significant saving.

The availability of new technologies like Big Data, cloud computing, cyber-physical systems, radio-frequency identification chips (RFID) and machine-to-machine communication will have a profound impact upon ship design and operation in the next 30 years. With faster technological advances, there will be a move towards delegating authority to allow the machine to perform a larger proportion of the tasks that are normally assigned to the human. In many instances these will be the tasks that may be referred to as dull, dirty and dangerous, prompting an alternative to be sought in order to replace the human and to ensure a higher level of safety and effectiveness.

There are varying degrees by which a person can delegate responsibility to a machine, according to the nature of the task and goal that they wish to accomplish and depending upon levels of both automation and autonomy built into a given ship. These ships are considered to be smart and data-driven. Broadly speaking, the first generation of 'smart' ships, which are already here, consist of human-delegated systems; the second consist of human-supervised systems with decision support advice; the third will consist of data analysis to process and make sense of the situation. These three will still require a human on board, though the vessel will be semi-automated or automated, and may be connected to an onshore centre. The fourth generation will be unmanned ships that are fully autonomous.

Today we are seeing the first generation of smart ships with features such as integrated ship area network – hardware-oriented ship operation and the convergence of wired and wireless communications on board ship. They also have technologies to allow the implementation of remote ship monitoring systems for machinery and equipment, as well as automated configuration management and one-way ship-to-shore communication.

It is anticipated that from 2020 onwards ships could become even smarter, incorporating technologies such as integrated ship area networks with interactive systems, plus ship-to-ship and ship-to-shore communication with data centres on shore to co-ordinate routes and priorities. They could also include integrated ship lifecycle management and operational efficiency management in accordance with local ship and engine conditions which would be coupled with environmental conditions. Additional technologies would include mission-based decision support systems for just-in-time arrival and departure; collision avoidance systems on board; cargo and passenger tracking; and satellite infotainment systems for crew and passengers to enhance their lifestyle on board ship.

From 2040 onwards we could see further advances in ship technologies that make the ships semi-automated or automated with little or no intervention. These would be fully connected to data-rich sources on board, in space, cyberspace or on shore, with access to powerful data-processing capability. This would allow data analytics to process and make sense of the situation (situation awareness) with other connected 'things'. These include: semi-automated or automated operation with few crew members and auto-maintenance scheduling; full situation awareness and ability to extract data to account for new operational situations without any preprogramming or preconfigurations; the ability to provide online information and reply to enquiries for regulation and operation compliances; and minimum crew requirements with little or no intervention necessary.

It is expected that unmanned and fully autonomous ships could start to appear from 2050 onwards with technology features as yet unseen in previous generations of ships. Unmanned and fully autonomous vessels could work independently or as a member of a fleet. They would have the ability to learn from other fourth-generation smart ships as well as having autoregulatory and operation-updating compliance.

The essential feature of these smart ships is that they all are data-driven, and connected both within themselves and with the outside world. They could fundamentally change the business model in the marine industry, in that bespoke information and data could be obtained 24/7. For example classification societies would be able to acquire data for safety and classification purposes or for other additional services a client may wish to pay for. Shipowners could access the full material state on the ship, and operators would have full control over operational data and performance data. Data-driven connectivity would allow flag states to obtain fully statutory compliance information, and port states to gather safety, cargo and personnel information.

These smart ships will be based on cyber-physical technologies that enable the building of data-driven and interconnected systems.
As a result, the maritime industry will need to reconsider its business model and transform to a data-driven one. This will affect the education and training of a new generation of naval architects, engineers, seafarers and managers. In the future, ship operations may be conducted entirely onshore and remotely manned by personnel with university degrees, developing into the need for doctorate degrees as ships become so smart and complex. Ship design and construction (including system integration) could become so sophisticated that few countries can master it, stopping the previous trends where shipbuilding has moved from a higher-cost country to a cheaper-cost one. This may also introduce structural changes to marine industrial organisations, to the extent that middle-level management could disappear completely from the pyramid, resulting in an hour-glass type of organisational structure connected by data analytic systems. Many new issues would arise and need to be addressed, such as cyber security and port operations. With ageing populations, rising wages and the availability of affordable enabled technologies, smart ships will slowly and surely become part of the routine shipping scene.

Who knows when the next shipping revolution will occur? Given the accelerating rate of technological change, and the pursuit of greater efficiencies, which has tended to reduce the time-lag between invention, innovation and wider adoption, it seems likely that this will occur sooner rather than later. But whenever it does, LR surveyors and engineers will still be working closely with builders, owners, operators and manufacturers to make sure it happens safely.

**End Notes**

1 'Working together for safer, more sustainable ships', LR *Horizons*, 27 (June 2009) p4.

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This has been a challenging but fascinating assignment. Attempting to tell the remarkable story of shipping technology since the late eighteenth century from a synthesis of the accumulated knowledge of so many maritime historians and other experts in various related maritime fields could never have been undertaken without the commitment, help and advice of countless other people. I am truly grateful to them all.

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**Nigel Watson**
Spring 2015

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To try to document the changing maritime world of the past 250 years in 300 pages has been a very challenging task, but our ability to draw on the extensive Lloyd's Register Foundation Library and Archive collection has enabled us to rise to the challenge. It is worth bearing in mind, though, that much of that historic source material, dating back to the eighteenth century and written when the UK was a leading shipbuilding and ship-owning nation, has a UK-centric focus, and this will inevitably have coloured some of our writing. So in order to keep the size of *Maritime Science and Technology: Changing our World* within reasonable bounds, we have taken the last 250 years at a scamper – but we nevertheless hope this book will inform you about people and events long since forgotten by many, and will spark your interest in further investigation of the subject. Finally, this book also looks toward the future, at what is in the offing for the maritime world. From our viewpoint, it is clear that the maritime industry has an interesting future as well as a fascinating past; I hope you enjoy reading about both.

**Barbara Jones**
April 2015

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Gold Rush San Francisco Harbour –Library of Congress, Prints and Photographs Division (HABS CAL,38-SANFRA,85—1).

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## Epic photographs

**Chapter:**

**1** Evening departure - Ambrose Greenway Collection

**2.** Steam coaster ***Rook*** loading coal - Ambrose Greenway Collection

**3.** Ship's wake - Ambrose Greenway Collection

**4.** Newly completed ***Bremen*** under tow - Ambrose Greenway Collection

**5.** Supertanker *Tina Onassis*, 1953 - Ambrose Greenway Collection

**6.** Lighthouse on Syros - Ambrose Greenway Collection

**7** *Glenearn*, King George V Dock, London - Ambrose Greenway Collection

**8.** Fawley oil terminal, Hampshire - Ambrose Greenway Collection

**9.** Launch of the ***Ocean Lady***, Dalian, 2009 - Maciej Wolaniecki

**10.** Boxboat silhouette - Ambrose Greenway Collection

**11.** *Costa Fascinosa*, Venice – Barbara Jones

**12.** Whale tail, Juneau, Alaska – Gareth Jones

**13.** Vehicle carrier ***Courage*** at night - Maciej Wolaniecki

**14.** Trinity House ***Alert*** - Maciej Wolaniecki

**15.** LR surveyor at work - Maciej Wolaniecki

**16.** Moss cargo tanks - Jack du Bois

**17.** Karl G. Jansky Very Large Array (VLA) radio astronomy observatory, New Mexico, USA - Gerard Gaal

# Photograph and illustration captions

Captions to the photographs and illustrations featured in the original hardback book.

## Chapter 1 – Towards a revolution

Epic image:
Evening departure - Ambrose Greenway Collection

The Rhinebeck Panorama, an extraordinary bird's-eye view of London dating from 1806–07.
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A large modern Maersk container vessel is more than 135 times bigger than the largest HEIC East Indiaman, *Earl of Abergavenny*, launched in 1796 and measuring 1,440 tons (bm).

The *Earl of Abergavenny* off Southsea by Thomas Luny
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The East Indiaman *Warley* by Robert Salmon, 1801
The ships of the HEIC such as the *Warley*, were the bulk cargo carriers of the 18th century. Built to maximise their cargo-carrying potential, they were usually more than four times the size of other cargo vessels of the period.

A drawing by Harry Cornish, a former Chief Ship Surveyor of LR, depicting the Blackwall shipyard of the very early 19th century. Shipbuilding in private yards depended upon the skill of their Master Shipwright. Apprentices trained under them for seven years, and ships were built to accepted practice.

Pierre Bouguer, a French mathematician who was interested in ship design, manoeuvres and navigation, developed a formula for calculating the metacentric radius, a measure of ship stability.

A three-masted barque in full sail by Samuel Henry Wilson RA, (fl. 1850–1870)
During the sailing vessel era, their rig, such as ship, barque, brigantine, snow or schooner, usually described the vessels. Rigs developed in complexity until the arrival of the steamship.

Anthony Deane
©*National Maritime Museum, Greenwich, London*
Harwich shipyard in the 18th century

*A brigantine in a calm sea* by John Cleveley the Elder
© *National Maritime Museum, Greenwich, London*

Frederik af Chapman
*Reproduced by kind permission of Sjöhistoriska museet*

Considered the first naval architect, Frederik af Chapman began work on his *Architectura Navalis Mercatoria* in 1765; it was published three years later.
*Reproduced by kind permission of Sjöhistoriska museet*

Gabriel Snodgrass

John Harrison was a clockmaker who invented the marine chronometer, a timepiece accurate enough to establish a ship's longitude at sea.
©*National Maritime Museum, Greenwich, London*

H4, one of Harrison's five prototype marine timekeepers, was the forerunner of all precision watches.
©*National Maritime Museum, Greenwich, London*

The ongoing construction of LR's Southampton Global Technology Centre shown in February, 2012.

## Chapter 2 – New marine technologies – iron and steam

Epic image:
Steam coaster *Rook* loading coal - Ambrose Greenway Collection

James Watt
© *National Portrait Gallery, London*

Thomas Newcomen's steam engine of 1712.
© *Bridgeman Image*

John Fitch's *Perseverance* was the first US-built steamboat, and was trialled on the Delaware River in 1787.

Fitch was granted his steamboat patent on 26 August 1791. This being the same day as James Rumsey, Nathan Read and John Stevens got theirs, Fitch could not hold a monopoly over the US steam industry. Subsequently, he travelled to France and later Britain hoping his steam engine would gain him an abundance of wealth; however this proved unsuccessful.
*Reproduced by kind permission of Architect of the Capitol*

*Coalbrookdale by Night* by Philip James de Loutherbourg, 1801, showing the Madeley Wood or Bedlam furnaces of the Coalbrookdale Company. A furnace and works had been at Madeley since 1109; the company was formed in 1709 and continued until 1796. This was the landscape of the early Industrial Revolution, iron ore, coal, water and steam being the drivers.
*© Science Museum/Science & Society Picture Library*

Robert Fulton
*© Bridgeman Images*

Scale model of Fulton's first experimental steamboat built at Paris in 1803.
*© Science Museum/Science & Society Picture Library*

William Symington, sponsored by Lord Dundas, built the stern wheel steamboat *Charlotte Dundas* which had a double-acting condensing steam engine built by James Watt. The vessel steamed for 18 miles in January 1803. In March that year she towed two 70-ton barges 20 miles along the Forth and Clyde Canal to Glasgow, taking just over 9 hours at an average speed of 2 miles per hour. The directors of the canal were concerned at possible erosion damage from the vessel, which was consequently withdrawn from service.

Boulton & Watt developed the steam condensing engine between 1763 and 1775.
*© Bridgeman Images*

Colonel John Stevens
*©Reproduced with kind permission of Stevens Family Collection. Special Collections, S.C. Williams Library, Stevens Institute of Technology, Hoboken, NJ.*

John Steven's *Phoenix*, built in 1808, which made the first sea-going voyage under steam, from Hoboken to Philadelphia.
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The *Clermont* was built by Charles Browne in 1807. The ship's name *Clermont* was first mentioned in a biography of Robert Fulton in 1817, written by Fulton's close friend, Cadwallader Colden – but there is no contemporary source of her being referred to by that name. Prior to 1817, she was known as the *North River Steamboat*.
*© Bridgeman Images*

John and Charles Wood introduced a scientific approach to shipbuilding and built the *Comet* in 1812. Considered the first commercially successful steamer in Europe, she took passengers between Glasgow and Helensburgh on the River Clyde.
*© Science Museum/Science & Society Picture Library*

The *Ferdinando Primo* was the first steamship to run a service in the Mediterranean. Launched on 24 June, 1818, she left Naples on 27 September for Livorno then Genoa and Marseilles.

*Rob Roy* inaugurated the regular steamer service between Greenock and Belfast in 1818. She was sold to the French Post Office in 1822 who renamed her *Henry IV* and used her on the Calais–Dover route.

The *Fighting Temeraire* tugged to her last berth to be broken up, 1838 by J M W Turner, 1839
This emotive painting by Turner portrays HMS *Temeraire*, second in command at the Battle of Trafalgar, being towed by steam tug from Sheerness to Rotherhithe to be broken up.
*© The National Gallery, London 2015*

William Symington
*© National Portrait Gallery, London, Collective Commons*

William Symington's steam-driven catamaran, which was trialled across the Dalwinston Loch, Scotland, in 1788.

William Symington's direct-acting steam engine of 1801.

*Britannia* by Robert Lloyd
*Reproduced by kind permission of Cunard*

The *Great Western* was the first steamship specifically designed to cross the Atlantic. She was launched by her builders, Patterson & Mercer, on 19 July 1837. On her maiden voyage she reached New York just four hours after the *Sirius*. Designed by Isambard Kingdom Brunel, she could carry 120 first-class and 60 second-class passengers. Her passenger saloon at 75 feet long was the largest and most luxurious yet built on any ship.
*Reproduced by kind permission of the ss Great Britain Trust*

Robert Seppings (1767–1840) by William Bradley
Robert Seppings was a naval architect who rose through the Royal Naval Dockyards to become Surveyor of the Navy from 1813. He invented the Seppings Blocks, a form of blocks and wedges for supporting a ship in drydock, which once removed allowed access to the keel, and also devised a system of diagonal framing in the construction of ships. Increasing the length of wooden ships gave them a tendency to hog, Seppings method ensured the whole framework was effectively braced against longitudinal strains. Influenced by Gabriel Snodgrass' introduction of iron fittings and knees to construction of the ships of the HEIC when timber became rare, he introduced these ideas to the Royal Navy.
*© National Maritime Museum, Greenwich, UK, Royal United Service Institution Collection*

John Wilkinson
*Reproduced by kind permission of Wrexham County Borough Museum & Archives*

In the late 18th century the UK government did not issue small denomination coins. This led to a shortage of coinage to pay low-paid workers' wages. Wilkinson employed over 1,000 workers and ordered tokens, known as 'Willeys', to pay them, producing them from 1787–1793. All of them showed a portrait of Wilkinson on one side and a celebration of one of his achievements on the reverse; a forgemaster, Vulcan with an anvil, a blacksmith or a cargo ship. The tokens were ordered by the ton.

John Scott Russell was a naval engineer and leading iron shipbuilder of the day; it was his yard that brought Isambard Kingdom Brunel's plans for the *Great Eastern* to fruition. Scott Russell's scientific approach led to him being seen as the father of the modern discipline of naval architecture. The *Flambeau* of 1839 was the first vessel to be designed using his wave line theory. He experimented to find a successful longitudinal framing method, starting with building the *Sirius* in 1834 and finishing with the *Annette* of 1862, the last ship built by his longitudinal framing method.

The steamer *Perth* which with her sister vessel *Dundee* was completed in 1834 to provide a 38-hour duration, fast packet service between the east coast of Scotland and London. These luxurious vessels with saloons decorated by Sir Horatio McCulloch, engines built by Robert Napier and hulls built by John Wood, could not put to sea in the depths of winter. They, like many other steamers, went into winter lay-up while sailing vessels undertook their service.

John Ericsson, a Swedish engineer, successfully exported his idea for a screw propeller to the US where it was adopted for the USS *Princeton*, the US Navy's first screw-propelled warship, commissioned in 1843. During the American Civil War he designed the USS *Monitor*, the first of her kind, a heavily armour-plated warship with a very large rotating gun. The Monitors sat so low in the water that they looked like floating gun platforms.

The *Archimedes* steamer, aquatint by William John Huggins
The *Archimedes* was launched by Henry Whimshurst in November 1838 for the Ship Propeller Company and was used to demonstrate John Ericsson's screw propeller. After trials and modifications she was compared with similar paddle-steamers by the Admiralty and was seen and evaluated by Isambard Kingdom Brunel when she toured British ports.
*©National Maritime Museum, Greenwich, London*

Francis Pettit Smith's original patent dating from 1836 and showing a screw propeller with two full turns, which he would later revise to one turn.

Robert Field Stockton was a US naval commander famous for capturing the state of California during the Mexican–American War of 1846–1848.

The 33 grt steamer *Robert F Stockton* was built by John Laird in 1838 for its namesake in order that he could demonstrate John Ericsson's inventive design of screw propeller to the US Navy.

Brunel's restored *Great Britain* in the Great Western drydock in Bristol, where she was originally launched in 1843.
*Reproduced by kind permission of the ss Great Britain Trust*

The use of advertisements and advertising cards to promote a shipping line or a vessel's sailings increased from the mid-19th century. By the 1880s companies were starting to use posters, but the colourful artistic posters designed by many of the well-known artists such as Kenneth D Shoesmith were from the 20th century.

*R & H Green Blackwall frigate Nile off Deal* by Stephen Dadd Skillet (1817–1866)
The Blackwall frigates were built at Blackwall by R & H Green for the East India trade, to replace the East Indiamen when the HEIC ceased its trading activities in 1833. The Blackwall frigates were finer and faster than their predecessors, with the appearance of a warship, retaining a quarter gallery and partially rounded stern. R & H Green, builders of the 1126-ton *Nile* in 1850, continued to build ships at Blackwall until 1907.

The three-masted topsail schooner *Susan Vittery*, attributed to Reuben Chappell (1870-1944)
Fruit schooners, or 'fruiters' like the *Susan Vittery*, were small, fast sailing vessels, usually with a combination of topsail and fore-and-aft schooner rig. They would sail to the Azores or ports in the Mediterranean to pick up perishable cargoes such as fruit, nuts or wine and return at high speed to ensure the cargo arrived in good condition for market. Their high hatch covers could be left open to ventilate the cargo in all but extreme weather.
*Reproduced by kind permission of Private collection, image courtesy of Whyte's*

The *Sovereign of the Seas* by John (Jack) Robert Charles Spurling (1870–1933)

The ongoing construction of LR's Southampton Global Technology Centre shown in April, 2012.

## Chapter 3 – The innovators

Epic image:
Ship's wake - Ambrose Greenway Collection

David Napier is considered to be one of the first men to have dedicated himself to marine engineering as a profession.
*Reproduced by kind permission of The Engineer*

The shipbuilding yard of William Denny and Brothers, Wood Yard, Dumbarton, 1850, showing the vessels: *Three Bells, Queen, Neptune, Prince Albert* and *Luba*.

William Denny began shipbuilding in 1814 on the bank of the River Clyde and founded a world-famous shipyard, Dennys of Dumbarton.
*©National Maritime Museum, Greenwich, London*

The compound engine of Pacific Steam Navigation's *Valparaiso* built in 1856, shown in side elevation and end elevation. Used on the company's South American service, the engines were so successful and achieved such economies on fuel that the company sent a further three of their ships back to the UK for re-engining with compound engines.

The forge at Thames Ironworks yard.
*©National Maritime Museum, Greenwich, London*

The School of Naval Architecture, within Portsmouth Dockyard, was completed in 1817, probably, according to the architectural historian Jonathan Coad, to the design of Edward Holl. Although the school closed in 1832, the building was useful to the Navy and survives to this day.
*Reproduced by kind permission of PRDHT*

John Rennie

The Annapolis Naval Academy was founded in 1845 by the then Secretary of the Navy, George Bancroft. It stands on the banks of the Severn River and on the shores of Chesapeake Bay, Maryland. The motto of the academy, devised by Park Benjamin Jr. and adopted in 1898 is *Ex Scientia Tridens* – Through Knowledge, Sea Power.

Augustin Francis Bullock Creuze (1800–1852)
Creuze was a respected naval architect and LR Principal Surveyor, who had attended the School of Naval Architecture, Portsmouth. The author of a number of articles including a treatise on shipbuilding in *Encyclopædia Britannica*, Creuze wrote in 1850 that it was too early for LR to produce rules for iron ships as this would deter shipbuilders from making improvements.
*Reproduced by kind permission of Warwick Sheffield*

Marc Isambard Brunel
*© National Portrait Gallery, London*

Isambard Kingdom Brunel
*©Bristol Museums, Galleries & Archives*

John Scott Russell was a leading iron shipbuilder of the period, and Isambard Kingdom Brunel's *Great Eastern* was built at his shipyard at Millwall, where she was launched sideways – itself an innovation – as a stern launch was impossible given her great length and the width of the river at that point. Work on construction began in February 1854. *Great Eastern* was the most remarkable ship built during the 19th century. She was twice as long as any other merchant ship and roughly eight times the size. Unsurpassed in size until the launch of Oceanic Steam Navigation's *Oceanic* in 1899, *Great Eastern* was designed to steam from Europe to Australia without refuelling, with bunkers holding 12,000 tons of coal. Innovations included longitudinal framing, a double bottom and propulsion by both screw and paddles. Never used on the intended service, however, she ruined her backers, her builder and several successive owners, her problems also contributing to Brunel's early death in 1859.
*©National Maritime Museum, Greenwich, London*

The Royal Mail Steamships *Clyde*, *Dee* and *Teviot* engraved by Andrew Maclure
*©National Maritime Museum, Greenwich, London*

John Scott Russell
*©Scottish National Portrait Gallery*

The *Leander* by John (Jack) Robert Charles Spurling (1870–1933)
The composite ship *Leander* was built in 1867 to the designs of Bernard Waymouth, LR's Principal Surveyor 1870–72 and Secretary 1872–1890. He also contributed to the design of several other significant ships and yachts, including the *Thermopylæ* of 1868, and the schooner yacht *Shamrock*. With his friend, the renowned yacht designer George Watson, he also designed the yacht *Vril*.

*Savannah* was the second steamer to be classed by LR. Built in 1818 in the United States, the *Savannah* was sent across the Atlantic in the hope that the Tsar of Russia would buy her. She was unable to carry enough coal for the voyage and her engines were used for just 85 hours, the rest of the voyage being undertaken by sail.

The four-masted barque *Thekla* by G F S Robinson
Sailing vessels continued to develop alongside steamers. With the advent of composite and then steel construction, their hull size increased as did the sail area and number of masts, as shown by this four-masted barque.

The *Beaver*, a steamer built in London in 1835, was the first steamship to reach the North Pacific when she arrived at the Hudson's Bay Company's Fort Vancouver on the Columbia River in 1836. She was used as a floating fur-trading outpost, working the waters of the Inside Passage from Puget Sound to Alaska.
*Reproduced by kind permission of the Vancouver Maritime Museum*

The ongoing construction of LR's Southampton Global Technology Centre shown in June, 2012.

### Chapter 4 – The metal screw steamer

Epic image:
Newly completed *Bremen* under tow - Ambrose Greenway Collection

Ironbridge, Staffordshire, has the world's first cast-iron bridge, built in 1779 to span the River Severn. The use of iron as a material changed the world in many ways; much stronger than wood, iron enabled much larger structures to be built.

The 1,610 grt *City of Glasgow*, built by Tod & MacGregor in 1850 for service with the Inman Line. She was in service for just four years until she disappeared at sea between Liverpool and Philadelphia in January 1854, with the loss of 480 lives.

*Roslin Castle* was a 4,280 grt iron screw mail steamer owned by the Castle Mail Packet Company, running on their service between the UK and South Africa. Built by Barclay, Curle & Co in 1883, her design typifies the steamers of the period. Originally fitted with a compound two-cylinder engine, she was re-engined in 1888 and fitted with a triple-expansion engine, increasing her speed by 3 knots to 15 knots.

The painting depicts her on 5 June 1891 leaving Dartmouth with the last mail to be carried from that port, after which Southampton became the embarkation port for mail.

During the Crimean War, the UK government requisitioned large numbers of ships for conversion to troop-carrying or logistical work. Many shipowners became unable to sustain their previous routes due to the shortage of ships.
*©National Maritime Museum, Greenwich, London*

Steamers needed vast quantities of coal, which was not always available at the traditional ports of call, particularly if coal did not form part of that country's natural resources. Coaling stations were established to feed the steamer's bunkers, and many shipowners supplied the coal for their own ships, often using sailing vessels for delivery. The replenishing of the coal bunkers of steamers was an arduous and dirty job that for many years in many parts of the world was undertaken by hand.

Armstrong made purpose-built hydraulic cranes that became essential for moving cargo more quickly as ships became larger. Some have survived such as this example at the Venice Arsenal.
© *www.e-architect.co.uk*

William Armstrong
© *National Portrait Gallery, London*

Alfred Holt was an innovative ship-owner who proved, by trial on the *Cleator*, that his version of a tandem compound engine driving a single crank, with a high-pressure boiler producing steam at 60 psi could achieve fuel savings of 40 per cent. The pressures used were lower than those for locomotives, the UK Board of Trade refusing to allow such high pressures (120 psi and more) because ships were still using salt water and not fresh. Earlier experiments with surface condensers had failed to lead to their general adoption but they were now reintroduced and accepted, and between 1870 and 1875 the number of compound engines in ships trebled.
© *National Museums Liverpool*

The 391 grt *Cleator* was built in 1854 by Cato & Miller, Liverpool, under the supervision of Alfred Holt. In 1864 Holt installed a compound steam engine and two 60 psi boilers – a steam pressure more than three times that of any other ship of the time.


The 2,700 triple-expansion engine constructed by R Napier & Sons, Glasgow, for the steamer *Aberdeen*, launched in 1881. The combination of this engine and Scotch boilers proved highly successful, supplying steam at 125 psi. The remarkable fuel economy achieved saw other owners adopting triple-expansion engines for their newbuilds, and many also sent their ships back to the shipyard for their ships to be re-engined. This development of engine design produced machinery of higher power and better fuel economy and enabled the size of ships to grow, especially on the major North Atlantic trade route from Europe to North America.
*Reproduced by kind permission of The Engineer*

In 1881 George Thomson & Co agreed to triple-expansion machinery being fitted to their new steamer *Aberdeen*, under construction at Robert Napier & Sons. She was the first commercial vessel to be fitted with the machinery and proved extremely successful on the Europe to Australia route for which she had been designed.

Alexander Carnegie

The harbour of San Francisco, crowded with shipping at the height of the Gold Rush. Many of the ships were abandoned, their crews also joining the rush for gold.
*Reproduced by kind permission of Library of Congress, Prints & Photographs Division*

Shipyard workers' skills had to change dramatically, first with the change from wood to iron and then again, to steel. An early shipyard had no machines apart from a wooden pole derrick, a sawyer's pit and a blacksmith's forge; shipwrights used simple wooden working tools and a steam chest for bending the planking. The arrival of iron and then steel construction introduced far-reaching changes. The materials required more than hand power to work, with steam power transmitted through overhead line shafts to drills, punches, sheers and plate-bending and joggling machines. Steam or electric jib cranes and rail connections aided the handling of the new materials. Riveting, initially done by hand, also progressed; in 1871 a portable hydraulic riveting machine was introduced, enabling riveters to put in 1,500 to 2,500 rivets a day, compared with 300 to 400 by hand hammer. At the end of the 19th century, there were further advances, with electric light and power, pneumatic tools, and gas cutting and welding. Within a lifetime, the shipyard had developed from a relatively unsophisticated operation into a highly technical factory setting.


Alfred Yarrow

The 1st Class Torpedo Boat *Sokol* built by Yarrow & Co for the Imperial Russian Ministry of Marine. Completed in January 1895, the boat measured 190 feet in length and 220 tons, and reached speeds of 30 knots during trials. *Sokol* was the first of her class, a further 26 being built in Russian yards between 1896 and 1903.

The first composite ship to appear in the *Register Book* was the *Tubal Cain* of 787 tons, which appeared in 1851 classed A1 with the notation 'Iron framed, planked'. LR's *Rules for Composite Ships* were developed over a number of years, and in 1866 surveyor Harry Cornish produced a series of 19 drawings illustrating the principle. The *Rules* were published in 1868.

At Port Said on 25 April 1859 Ferdinand de Lesseps broke the ground for the building of the Suez Canal. Ten years later, on 17 November 1869, the Khedive of Egypt formally opened the canal, which was to have a major and immediate effect on shipping, especially coupled with the development of the compound engine. The reduced distance from Europe to the Far East enabled steamers to compete economically with sailing ships, driving them into other trades. The distance from London to Singapore, for example, dropped from 11,733 to 8,247 miles, nearly a 30 per cent reduction.

Ships passing in the recently completed Suez Canal.

Inman Line Trading card.

Allan Line's *Buenos Ayrean* was the first steel vessel on the South Atlantic service.

*Ma Roberts* was the world's first steel vessel and was constructed by John Laird and then broken down into manageable pieces that were conveyed by ship to the African coast, and then by porter and wagon to the Zambezi river, where she was reassembled. This was not unusual; many small vessels were exported in this way.
*© Royal Geographical Society*

Anglo-American Oil's schooner-rigged tank barge *Navahoe* under construction in 1906. Her auxiliary engines were used for pumping and heating her cargo of crude oil.

Charles Parsons
*Reproduced by kind permission of The Engineer*

*Turbinia* was a small vessel built by Charles Parsons at Wallsend to demonstrate the potential of his steam turbine. After some modification, she steamed through the Spithead Diamond Jubilee Naval Review in 1897 at 34.5 knots.

Cavitation showing Parsons' original experiments into advanced stage cavitation at 1800 revolutions.

Norddeutscher Lloyd's *Kaiser Wilhelm der Grosse* was launched on 4 May 1897 by A G Vulcan, Stettin. At 14,349 grt she was the world's largest liner and Germany's first Blue Riband winner. With a pair of four-cylinder triple-expansion engines developing 28,000 ihp, she could travel at 22 knots, carrying 332 first class passengers, 343 second and 1,074 third. Fitted in 1900 with radio with a range of 25 miles, she was one of the first ships to adopt that technology.

The *Mauretania arriving in New York Harbour* by John Stewart

William John Macquorn Rankine, *A Manual of the Steam Engine and Other Prime Movers* (Glasgow, 1859)

The ongoing construction of LR's Southampton Global Technology Centre shown in July, 2012.

## Chapter 5 – Specialisation shrinks the world

Epic image:
Supertanker *Tina Onassis*, 1953 - Ambrose Greenway Collection

Coal was the fuel that drove the steamship, and Cardiff was known as the coal and shipping metropolis of the world. The first steamer owned in Cardiff was the *Llandaff*, built in 1865 at a time when coal exports from South Wales stood at around 2 million tons per year. By 1910 there were 250 tramp steamers owned in the area, and the pinnacle of its coal exports came in 1913 when 10.7 million tons of coal were shipped around the world. The *Edward Williams*, shown here, was built in 1871, and by 1886 was owned by Maclay & McIntyre, a Glasgow company that shipped Welsh coal to Algoa Bay in South Africa, returning with ore from the Mediterranean.

Cargo waiting on the quayside for loading onto a steamer.

Unloading coal into lighters from William Cory & Sons *Corstar*. All cities had an insatiable demand for coal, and at the height of the trade Cory's colliers shipped over 5 million tons of coal, coke and patent fuel each year. The colliers' cargoes were transhipped to lighters and barges to be taken up rivers such as the Thames and Medway to towns and cities, and overland by railway.

Brunel's *Great Eastern* found use as an early cable layer, laying cables from the UK to Newfoundland. Many cable-laying companies were set up in the latter part of the 19th century, their cables criss-crossing the world and dramatically reducing communication times. The image shows the winding of the cable into the drums contained in the hold.

The *John Bowes* is regarded as the first truly successful steam collier. In less than a week she could do the equivalent of the work done by two sailing colliers in a month. Built in 1852, *John Bowes* was proof of the durability of iron-built ships, lasting 81 years under various owners and flags.

The end of the 19th century saw the introduction of several patent designs of steamer including the trunk deck, tower deck self-trimmer, arch deck, monitor, American whaleback, Bredsdorff's self-trimmer and the Christensen oval ship. The best known was the turret, designed at Doxfords by its Chief Designer, Arthur Haver, who called it after the deck erections on the American whaleback. *Turret*, delivered in 1892, became the first of 183 to be built, the last being *Orangemoor*, delivered in 1911. The shape of the hull threw water off before it reached the turret deck and hatches. The vessel shown here is the 3,135-ton *Orange Branch*, loading frozen meat for South Africa.

Red Star Line was well known for carrying passengers between Europe and the USA.
*©Lowie De Peter + Michel Wuyts/Stad Antwerpen*

Ludvig Nobel (1831–1888)

Alfred Nobel (1833–1896)

Oil began to be exported from 1873 from the oilfields of Baku on the western shore of the Caspian Sea, an initiative started by Robert and Ludvig Nobel. Caspian oil was either taken by way of the Volga and canals to the Baltic, the Mariinsky Canal near St Petersburg being the decider as it limited the size of the tankers, or shipped from Black Sea ports. Commencing with the *Zoroaster* in 1878, the brothers built a fleet of sea and river tankers. *Zoroaster* was designed by Ludvig Nobel and constructed at the Motala works shipyard in Norrköping, Sweden. The Nobel tankers had iron hulls double-riveted to prevent leakage, and double bulkheads between the boiler room and the cargo tanks. The family as a whole became very wealthy; Robert and Ludvig's younger brother, Alfred, left a bequest creating the Nobel Prizes, substantial sums which have been awarded nearly every year since 1901.

The *Glückauf* was one of the first ocean-going oil tankers to have oil pumped directly into her hull. She is considered to be the prototype of the modern tanker, her cargo space divided by a single longitudinal bulkhead and several transverse ones. Launched by Sir W G Armstrong Mitchell & Co on 16 June 1886 for Deutsche-Amerika Petroleum, she was short-lived, stranding on Fire Island, 50 miles from New York, on 24 March 1893.

Canadian oilfields. The first oil wells were drilled onshore and it would be a number of years before wells were moved offshore, and even then the wells were located only in shallow water. The yield of oil during the early 1860s was far in advance of demand, and much oil went to waste, flowing into creeks and rivers, causing pollution. In 1862 oil sold for 10 cents a barrel; there was no export demand and little home demand as lamp manufacturers and others had yet to catch up with the new fuel becoming available.

The launch of HMS *Sans Pareil* on 9 May 1887.
*©National Maritime Museum, Greenwich, London*

A sketch of every ship built by Thames Ironworks, drawn to scale possibly by a draughtsman at the works.
*©National Maritime Museum, Greenwich, London*

Ferdinand Carré (1824–1900) was a French engineer who continued the work of his brother Edmond, developing an absorption-refrigerating appliance based on the gas vapour principle using water and ammonia. Patented in 1859, the machine was first used at sea on the *Paraguay* in 1876.

Clan Line's *Clan MacDougall* with a cargo of frozen carcasses being unloaded at the London docks.

The *Frigorifique*, a 613 grt vessel with refrigerating machinery installed on board, carried a cargo of beef from Buenos Aires to Rouen in 1877, maintaining the meat in a reasonable condition.

*Elderslie* seen here loading cargo at Sumpter Warf, Oamaru, New Zealand. *Elderslie*, built at Jarrow in 1887, was the first ship built especially for the carriage of frozen meat from New Zealand.
*©National Maritime Museum, Greenwich, London*

Ireland's 1846 potato famine and the consequent emigration of over 1 million people within six years called for a large shipping capacity. This was followed later in the century by a massive and growing migrant flow, which peaked in the early 20th century, as people either fled from oppressive European regimes or searched for a better life in the New World. Emigrants in third class or steerage travelled in very basic conditions with little space or comfort, and often suffered from disease during the arduous voyage.
*©Norway Heritage Images*

The advent of the steamship heralded another previously unforeseen use for ships, cruising, which turned out to be an excellent way of employing ships when their regular routes were unprofitable. Cruising increased in popularity, eventually leading to ships being built specifically for the cruise market.

The ongoing construction of LR's Southampton Global Technology Centre shown in October, 2012.

### Chapter 6 – Science, standards and safety

Epic image:
Lighthouse on Syros - Ambrose Greenway Collection

1894 saw the commissioning of the Russian Naval Administration Towing Tank, now called the Federal Unitary Enterprise Krylov State Research Centre and known as the Krylov Centre. The towing tank was the first in Russia and the sixth to be built in the world. Originally built for ship model tests to find engine power requirements for specific speeds and hull lines, the centre has grown dramatically in its 120 years and has now diversified into fundamental research and design appraisals for ships and structures in marine and inland waterway technologies, and investigating design solutions related to the offshore oil and gas industry. LR has collaborated with the Krylov Centre on some projects.
*Reproduced by kind permission of the Krylov Centre*

Aleksey Nikolaevich Krylov (1863–1945 was a Russian naval engineer and applied mathematician who investigated the deviation of the magnetic compass, put forward the theory of the gyroscope and investigated the theory of the oscillating motions of the ship, proposing gyroscopic dampening for damping the roll. He became the Acting Superintendent of the Naval Administration Towing Tank while working on ship floodability problems in 1900. In 1944 the tank was renamed in his honour.

Admiral Alexandrovich Popov (1821–1898) was an early supporter of the need for model testing tanks. He was a Russian naval architect and designer of the circular coastal defence vessels that became known as 'Popovkas'. His radical idea was supported by Sir Edward Reed, and the Imperial Russian Navy proposed using them in the Black Sea and the Sea of Azov. The intention was that the circular design would provide a stable gun platform. Only two of the ten originally proposed were built – and they proved impracticable, with a tendency to spin when their guns were fired, even with their rudder hard over and their six propellers contra-rotated. However, his design for the Imperial Russian Royal Yacht *Livadia* was more successful. Built in 1880 by John Elder & Co, Govan she proved to be a very comfortable and stable vessel.

HMS *Captain* was a ship-rigged, iron turret ship driven by double engines developing 5,400 hp. She was completed for the Royal Navy in April 1870 by Laird Brothers, Birkenhead – but inadequate supervision during her build led to design and construction errors that led in turn to disaster. She was eventually 735 tons heavier than designed, reducing her freeboard to 6' 6" and raising her centre of gravity by 10", yet during her trials the objections by Sir Edward Reed, Chief Constructor of the Royal Navy, were overruled. On the night of 6 September 1870, she hit a gale off Cape Finisterre and by midnight was heeling by 18 degrees; before her sail area could be further reduced she rolled further, capsized, and sank.
*Reproduced by kind permission of The Engineer*

*Laconia* was the first British passenger liner to be fitted with Frahm anti-rolling tanks when she was constructed by Swan, Hunter & Wigham Richardson Ltd., in 1911. She and her sister vessel *Franconia* were also the first in the Cunard fleet to have both a gymnasium and moveable chairs in the main dining room. Until that time, fixed chairs had been used in the public areas.
*Reproduced by kind permission of Cunard*

Following the tragic loss of HMS *Captain* in 1870, Froude undertook rolling trials for HMS *Devastation*, the Royal Navy's new mastless turret ship. The first trials were with two scale models in Froude's testing tank, then sea trials with the ship which included enforced rolling by 400 men running across the deck.
*©The Maritime Photo Library*

Ludwig Prandtl (1875–1953) was a German physicist who by 1901 was Professor of Mechanics at Hannover, researching the theoretical basis for fluid mechanics. In 1904 he introduced his concept of a boundary layer adjoining the surface of a form moving through water or air, leading to the science of aerodynamics and the understanding of how streamlining can reduce friction and thus drag. In 1925 he became Director of the Kaiser Wilhelm (later Max Planck) Institute for Fluid Mechanics.
*Reproduced by kind permission of DLR-Archiv Göttingen*

The cylindrical slide rule invented by George Fuller; were the slide rule to have been in linear form it would have been 30 feet long.

William Denny (1779–1833)
*©National Maritime Museum, Greenwich, London.*

At the National Physical Laboratory, Teddington, the first tank was constructed in 1911 using £20,000 provided by the shipbuilder Alfred Yarrow. It was used to test new designs of ships, and to investigate unusual hydrodynamics problems using paraffin wax models, moulded and shaped to form an exact scaled replica of the design under consideration. Sir James Lithgow donated further funds in 1938, enabling the building of a cavitation tunnel. The facility has also undertaken assessments of features such as bulbous bows.
*Reproduced by kind permission of NPL*

Anchor Line's elegant *City of Rome*, which was launched in June 1881. She was the first liner to be built with three funnels.
*Reproduced by kind permission of dalmadan.com*

William Fairbairn

Benjamin Martell (1825–1902)

Samuel Plimsoll (1824-98) was a coal merchant and UK Member of Parliament. Capitalising on shipowner James Hall's concerns about safe loading of ships and ideas for a load line, Plimsoll requested a Commission of Enquiry, which was granted in 1873. Its members included William Denny and George Duncan, a shipowning member of LR's General Committee. The resulting Merchant Shipping Act, 1876, required all foreign-going vessels, coasting vessels over 80 tons and foreign ships sailing from British ports to have their deck lines and load lines marked. Yet there was still no guidance for the assigning authority, nor any formula for the calculation, and the shipowner decided on the position of the marking of the load line.
*Reproduced by kind permission of Andy Lamb of the Northern Echo*

The iron-hulled emigrant ship *Tayleur*, built by William Rennie in 1853, is commonly referred to as the 'First *Titanic*' due to the great loss of life caused by her sinking in January 1854.

The British Wreck Commissioner's Inquiry into the loss of the *Titanic*, overseen by Lord Mersey, was held from 2 May to 3 July, 1912, at the London Scottish Drill Hall in Buckingham Gate, London. A United States Senate Inquiry chaired by Senator William Alden Smith was held in New York and Washington.

Built by Harland and Wolff in 1911, the 46,328 grt *Titanic* was the largest vessel afloat at that time. Her tragic sinking on her maiden voyage in April 1912, when more than 1,500 people lost their lives in a flat calm, was the precursor for the first SOLAS regulation.

The *Austral* was a 5,524 grt passenger steamship that was built by John Elder & Co in 1882. That November *Austral* sank in Sydney Harbour; five of her crew died. She was later raised and refitted.
*Reproduced by kind permission the Australian National Maritime Museum*

The Lloyd's signal station located at Bass Point, Cornwall, built in 1901 to experiment with Marconi radio transmissions. The building still survives, and is the oldest surviving purpose-built wireless communication station in the world.
*Reproduced by kind permission of photoeverywhere*

Dr Samuel J P Thearle (1846–1913)

White Star Line's *Teutonic* under construction at Harland & Wolff, Belfast in 1889.

*Navahoe* was used to carry oil across the Atlantic between Baton Rouge and Thameshaven, towed by the tanker *Iroquois*. They made 148 crossings before the outbreak of the First World War, during which they transferred to the Texas–Halifax route. Back on the Atlantic run after the end of the war, *Navahoe* continued until 1930, when she became a storage barge at Caripito on the San Juan River, Venezuela; the tankers were too big to load to their marks at the oil terminal upriver, so they would complete their loading from the *Navahoe*. In 1936, at the end of her life, she was towed out to sea by one of the tankers she usually loaded, and scuttled.

The ongoing construction of LR's Southampton Global Technology Centre shown in December, 2012.

## Chapter 7 – The impact of shipping technology on the nineteenth-century world

Epic image:
*Glenearn*, King George V Dock, London - Ambrose Greenway Collection

By 1850, the UK was producing 40 per cent of the world's manufactured goods, including the products of the cotton mills shown here. Raw cotton was imported via ship to the mills in the UK for manufacturing, and a high percentage of the finished product was then exported around the world, again via ship. Most other manufacturing industries in the UK and the Western world also benefited from the impact of faster, larger and better-built ships to import raw materials and export their goods.
*Reproduced by kind permission of the Postcard collection of Maggie Land Blanck*

As the industrial nations grew in terms of both their industries and their populations, so did their ports and facilities, in order to handle the vast increase in the cargoes. Some ports eventually moved from their traditional city-centre locations to places further downstream where there was space for the new cargo-handling equipment such as cranes, gantries and derricks, plus access to railheads and road networks, and room to build larger warehouses. The move also meant, of course, that the port could accommodate bigger ships.

The refrigerated cargo ship had a highly positive impact on the meat-producing countries such as Argentina, Australia and New Zealand; they could now grow their production, and therefore their economies, by exporting their foodstuffs to

ready markets in Europe. Refrigerated ships also had a beneficial impact on the livestock trade, meaning fewer live animals undergoing the stress of the voyage, the animals being slaughtered in their country of origin and their carcasses frozen before export.

Smaller ports were slow to adopt new loading technology as can be seen in this image of potatoes being unloaded by hand, in baskets.

Orient Line's steamer *Orient* shown off Gravesend. She was on the Australia–London service, and in 1880 made the voyage from Adelaide to London in 31 days, a remarkable 10 days faster than her competitors.

David Napier
*Reproduced with kind permission of The Engineer*

Robert Napier

The *Lucania* was a Cunard liner built by Fairfield Shipbuilding and Engineering Co in 1893, with triple-expansion engines developing 30,000 ihp. In May 1894 *Lucania* averaged 21.75 knots on her Atlantic crossing and on her best day's run achieved no less than 562 nautical miles. She was the first Cunard liner fitted with Marconi radio equipment, and in January 1909 was one of five vessels that answered the distress call when the passenger liners *Florida* and *Republic* collided in dense fog south of Martha's Vineyard.
*Reproduced by kind permission of the British Mercantile Marine Memorial Collection*

The first class dining room of the Cunard liner *Campania*, sister to the *Lucania*. *Campania* was sunk in collision with HMS *Glorious* on 5 November, 1918.
*Reproduced by kind permission of Cunard*

Cargo loading and unloading methods changed rapidly and radically to keep up with the enormous cargo loads now going through the ports of the world. Small ports with few facilities and accommodating small ships and sailing vessels still loaded and unloaded by hand – but elsewhere steam cranes pioneered by William Armstrong began to appear, plus chutes and conveyors. Even so, a ship could be tied up in port for weeks loading and unloading cargo.

All shipping companies whether their fleets were sailing ships, or steamers and motor vessels, had their own house flag and in the latter case, funnel colours. There was enormous variety as can be seen in the selection shown above and the image right, which depicts P&O's house flag with a flag signal.

The ongoing construction of LR's Southampton Global Technology Centre shown in February, 2013.

## Chapter 8 – The motorship and the oil tanker

Epic image:
Fawley oil terminal, Hampshire - Ambrose Greenway Collection

Many experiments in the evolution of the marine boiler were undertaken in the latter part of the 19th century and the early 20th, but until steel came into more common use boilermakers were unable to achieve the build quality and longevity required – iron tubes corroded rapidly and were subject to frequent build-up of scale. Yarrow, Thornycroft, Jacques-Augustin Normand and many others investigated the problems. The Scotch boiler, introduced in 1862, was a breakthrough when allied to other improvements such as the surface condenser; the boiler enabled fresh water to be used and reused, as its cylindrical shape could withstand the higher pressures inherent in the more efficient engines; economical compounding required a pressure of 60 psi or more to demonstrate the full potential of the economies. The *Great Western* of 1837 had operated at a boiler pressure of 4 psi while in 1874 the White Star Line's *Britannic* operated at 70 psi. By 1904 the water-tube boiler (Yarrow type), where many tubes form the main part of the heating surface of the boiler, were being fitted in fast merchant ships. The *Queen Mary* had 24 Yarrow water-tube boilers, and her steam was supplied at 400 psi at a temperature of 371°C. However, despite the efficiency of the water-tube boiler, the Scotch boiler remained in use for many years due to its simplicity and low cost.

*Kaiser Wilhelm II* was a passenger liner built by AG Vulcan in Stettin in 1903 for Norddeutscher Lloyd's express service. With a tonnage of 19,361 grt, not only was she one of the largest vessels of her type, but she was also one of the highest powered ships that used steam reciprocating engines. The vessel was in service for 37 years until broken up at Baltimore in 1940 under the name *Monticello*.

The *King Edward*'s steam turbines made by Charles Parsons. The casings are made of cast iron, the rotors inside are forged and set with thousands of handmade brass blades.

The beginning of the 20th century saw the continued technical development of machinery; by this time the simple single-expansion engine had given way to compounding and then triple expansion. In triple-expansion engines, steam is used three times, going from a high-pressure cylinder, through an intermediate-pressure cylinder and finally into a low-pressure cylinder, the pressure being reduced in each stage as the steam expands. The size of North Atlantic passenger liners was outpacing engine technology, resulting in giant quadruple-expansion engines called cathedral engines. Further developments led to the steam turbine where steam expands past fixed and rotating blades, making a rotor turn at high speed. This opened the way for more power, particularly when reduction gearing between the turbine and the propeller enabled the turbines to run efficiently at the higher speeds that were unsuitable for the propellers.
*Reproduced by kind permission of The Steamship*

The pattern used for casting the *Queen Elizabeth 2* steam turbines. Casting is the process of turning molten metal into a specific shape and the patternmaker makes a pattern to the engineer's specification. Sand is then poured around the pattern and compacted, and the pattern removed. Molten metal is poured into the gaps left by the removal of the pattern and allowed to cool forming the cast.

Rudolf Diesel's original patent application.

Det Østasiatiske Kompagni's *Selandia*, together with her Diesel engine.
*Reproduced by kind permission of Historical Archiv of MAN Augsburg*

The 4,196-ton tanker *Paul Paix* was completed in November 1908 using the Isherwood System for longitudinal framing. Joseph Isherwood had been an LR surveyor from 1896 to 1907, when he left to develop his innovative system and the Arcform hull. *Paul Paix* survived the war although damaged twice by mines, first on 24 December 1916 off Mumbles Head when in ballast from Dunkirk to Swansea, and then on 10 April 1918 off Start Point en route from Rouen to Plymouth.

The 2,332 grt three-cylinder steam reciprocating tanker *Azov* was launched on 15 February 1892 by Armstrong, Mitchell & Co Ltd for Azov SS Co Ltd. An example of an early tanker, she traded for many years for a variety of owners before running aground on 30 April 1925 off Cape Hogan when carrying molasses from Havana to Montreal.

The *Thomas W Lawson*, by LR Chief Ship Surveyor Harry Cornish
Sailing ship technology continued to develop such as steam winches for hoisting and trimming sails. The *Thomas W Lawson*, of 1902, was the only seven-masted schooner ever built. An American coastal oil trader, she was chartered to carry paraffin oil across the Atlantic in 1907. She ran ashore near the Isles of Scilly on 17 December when sheltering from bad weather. All but three of her crew were lost.

In the first decade of the 20th century welding was only used to repair boilers and hulls. In the autumn of 1917 welding work was investigated by the Admiralty and LR and testing undertaken at Portsmouth Dockyard, Cammell Laird, Birkenhead and elsewhere. The investigations showed that welding could save up to 25 per cent in time and material, and as a result, this 125-foot cross-Channel barge was completed in 1918 using welding technology supervised by LR.
*Reproduced by kind permission of The Engineer*

By December 1918 LR had published its draft regulations for applications of electric welding to ship construction, and had also published details of tests on arc-welded joints. The images from these experiments show the method employed to measure modulus of elasticity, arrangement of apparatus for making alternate stress tests on bar specimens and arrangement of apparatus for making alternating stress tests on flat plate specimens.
*Reproduced by kind permission of General Electric*

The 15,357 grt motor ship *Svealand* and her sister vessel *Amerikaland* were built in 1925 for their Swedish owners by Deutsche Werft Hamburg; at the time they were the world's largest bulk carriers. Their four-stroke, single-acting 1,818 nhp engines were built by Allgemeine of Berlin. Designed to carry ore through the Panama Canal from Chile to the world's largest steel plant at Sparrow's Point, Maryland, USA, the ships were not fitted with cargo-handling gear; the derricks along the side were to assist in raising the steel hatch covers. *Svealand* traded until broken up in 1969.

Work on the Panama Canal was completed on 7 January 1914, when the old French crane ship *Alexandre La Valley* became the first vessel to make a complete transit. The canal was officially opened on 15 August. The canal opening, linking the Atlantic and Pacific oceans without the need to make the treacherous voyage via Drake's Passage and Cape Horn, had a fundamental effect on world shipping operations, saving operators thousands of miles and revolutionising world shipping patterns with associated economic gains.

American Elmer Sperry started work on his gyrocompass from 1896, building on Leon Foucault's invention of the gyroscope. Until then, the magnetic compass had been used, but it was not very reliable, being affected by metal hulls and outside influences, and less than helpful at high latitudes. However, the gyrocompass, located in the most stable part of the ship to help it cater for her roll and pitch, unfailingly indicated true north. Its readings were transmitted to repeaters located near the wheel, on the bridge wings under the radio direction finder and other locations. A link to a course recorder plotted the ship's course and time. The invention was trialled in 1911 on the Old Dominion Line's *Princess Anne* between New York and Hampton Roads, and then installed aboard USS *Delaware* and, from 1918, Cunard Line's *Aquitania*. Sperry also invented the gyro pilot; the first crossing of the Atlantic by a ship completely under gyro pilot control was undertaken by Standard Oil's tanker, *W H Tilford* in 1922.
*Reproduced by kind permission of Hagley Museum and Library*

Fin stabilisers were quickly adopted for large passenger ships such as Norddeutscher Lloyd's *Bremen*, and retrofitted to those already in service, increasing passenger comfort.

A fin stabiliser.
*Reproduced by kind permission of wondersofworldengineering.com*

The tanker *Lucigen* was typical of those built early in the 20th century. Launched in November 1908 at Armstrong, Whitworth's Low Walker yard, she measured 4,954 grt. She continued in service until 1946, when after wartime duty as a depot ship at Lagos, she was sunk as a target.

Guglielmo Marconi

Marconi undertook many of his experiments onboard his yacht *Elettra*.

By 1909, 404 ships were fitted with wireless, the same year the passenger liners *Florida* and *Republic* collided in fog. *Republic*'s wireless operator broadcast the first ever distress signals – answered by the liners *Baltic*, *Furnessia* and *Lorraine*. The following year, the murderer Dr Crippen was recognised on board Canadian Pacific's *Montrose*, and a wireless message alerted police to meet the ship and arrest him on arrival in Canada.

The 10,627 grt motor tanker *G. S. Walden* was built in 1935 by N V Rotterdam Droogdok Mij, for Oriental Tankers, Hong Kong. She was the first tanker to be built to Isherwood's Arcform system of longitudinal framing although three cargo vessels had previously been built to the system. She was classed by LR, her construction method detailed in the *Register Book*. *G. S. Walden* was long-lived – she survived two torpedo attacks in the Second World War and was finally broken up in 1962.
*Reproduced by kind permission of TIB Hannover*

A Shell Tankers vessel during the Second World War.

Tanker design. From the earliest days of the modern tanker, the majority were designed with the superstructure aft, as now. Accommodation and bridge amidships was a design feature that became common during the 1950s. Tankers shown; *Hellespont Alhambra, British Respect, Narragansett, Azay-le-Rideau, Manhattan, Murex* and *Spyros Niarchos.*
*Narragansett and Murex reproduced by kind permission of the British Mercantile Marine Memorial Collection, Hellespont Alhambra reproduced by kind permission of Fotoflite*

The *Dominion Monarch* was the most powerful motor liner of her time. Completed in 1939 she had four, five cylinder, two-stroke single-acting Doxford Diesel engines producing 32,000 bhp.

The ongoing construction of LR's Southampton Global Technology Centre shown in February, 2013.

### Chapter 9 – Energy, specialisation and bigger ships

Epic image:
Launch of the *Ocean Lady*, Dalian, 2009 - Maciej Wolaniecki

The *Megara,* built to LR class ✠100A1 in 1929, was ordered by N.V. Petroleum Maatschappij 'La Corona' and converted to carry the first bulk cargo of LPG in 1934.

The *Rasmus Tholstrup* was completed by Marstrands MV, Denmark, in 1953. She was the first purpose-built LPG carrier and was originally fitted with 12 vertical tanks with a total capacity of 600 cubic metres. In 1959 she was lengthened from 165 feet to 199, and her 12 vertical tanks were replaced by three spherical ones. Shown at Fawley, Southampton Water, UK, circa 1970.
*Reproduced by kind permission of ChasB*

Launch in June 1963 of the *Methane Princess*, built by Vickers-Armstrongs, Barrow-in-Furness, UK; she entered service the following year.

*Birthe Tholstrup* a LPG carrier built in 1962 by Aarhus Flydedok and Maskinkompagni, for Kosan Tankers of Copenhagen.

Blockade ships sunk during the Suez Canal conflict, shown lying in Port Said at the Canal entrance on 26 November 1956.
*©IWM (MH 23543)*

Grain being loaded in an open hatch bulk carrier (OHBC) or conbulker.

The OBO *Horyo Maru* built in 1967 by Ishikawajima-Harima Heavy Industries Co Ltd, Japan. Shown clearly on deck are the pipes for oil and the cargo hold hatches for bulk.

The workhorses of the sea. The focus of this book is on the large ships of the world and the impact they have had on the global economy. However, there are many other types of ship, and the following ten captions give an insight into the diversity of the shipping industry.

Hellenic Seaways high-speed catamaran ferry *Highspeed 4*, which can carry 1,004 passengers and 100 cars at a top speed of 35 knots.

The Portuguese Navy sail training ship, the barque *Sagres*, built in 1937 by Blohm & Voss, Hamburg, for the Kriegsmarine; since 1961 she has been owned by the Portuguese Navy. Her three masts carry 2,000 square metres of sail, and in 2010 she circumnavigated the globe.

The Corporation of Trinity House's tender *Galatea*, designed with a multiplicity of capabilities including buoy handling, wreck marking, towing, and multibeam and side scan hydrographic surveying. Other features of the vessel include a moon pool (providing sheltered access to the sea), a Dynamic Positioning System (DPS, a computer-controlled system that keeps the ship on course and in position) and a helipad.

*Cable Innovator*, built in 1995 by Kvaerner Masa of Finland, is the largest vessel of her kind, specifically designed to lay fibre-optic cable. She has DPS and, enabling her superb manoeuvrability, four thrusters; at the stern two 900 kW 12t KaMeWa tunnel thrusters, and at the bow a 1,200 kW tunnel thruster and a 2,000 kW White Gill jet thruster.

The gas turbine cruiseferry *Finnjet*, built by Wärtsilä to operate on the route from Helsinki to Travemunde on Germany's Baltic Sea coast. Travelling at up to 33 knots, she covered the distance in just 22 hours; when scrapped in 2008, she was still the fastest ferry in the world.

The lo-lo/ro-ro vessel *Christopher Dean*, built in 1980 by Miho Shipyard, Shimizu, Japan, loads and unloads via her stern ramp.

*Mighty Servant 1*, one of Dockwise Shipping BV's semi-submersible heavy load carriers. These heavy lift vessels can take on water ballast to drop to a level enabling their load to be moved aboard quickly and easily, then release the water to rise to their normal sea-going level.

RMS *St Helena* is a combiliner, carrying all the mail, goods, supplies and passengers required by her island namesake, whose airport has yet to be commissioned. This 6,767 gt ship – one of the two remaining vessels still bearing the venerable Royal Mail Ship (RMS) prefix (the other being the *Queen Mary 2*) – used to run to St Helena and Ascension Island from the UK, but now serves them only from Cape Town.

The 3,092 gt general cargo vessel *Wilson Humber*, built in 1999 by Begej Shipyard, Zrenjanin, Serbia, for Wilson EuroCarriers.

P&O Ferries' *Pride of Kent*, completed in June 1992, and capable of carrying 2,000 passengers together with 650 vehicles or 120 trucks.

The ore carrier *Cassiopeia* built in 1956 by Kockums Mekaniska Verkstads AB – Mälmo, Sweden, shown arriving at Durban in July 1960. Launched in 1962, the *Besseggen* was installed with three Munck industrial cranes adapted to run up and down on tracks on the vessel's sides with crane roofs and curtains for improved rain protection. Lighter chain lashings were fitted for deck cargoes, and inflatable dunnage used to secure and stabilise cargo in the hold. Used by the Campbell River Mill for transporting newsprint to the US, the *Besseggen*'s pioneering design with a vacuum-handling device sped up loading and discharge.
*Reproduced by kind permission of Vancouver Maritime Museum*

Baltimore Bethlehem-Fairfield Shipyard where 350 *Liberty* ships of the standard EC2 type design were constructed between 1941 and 1945. During the war over 2,700 *Liberty* ships, nicknamed 'Ugly Ducklings', were built in the US.
*Reproduced by kind permission of the Library of Congress, Prints & Photographs Division, FSA/OWI Collection, [LC-USW3-026455-E]*

LR's specialist materials laboratory provides a wide range of inspection, failure investigation and advisory services worldwide. Shown is fatigue fracture in welded plate initiating from lack of weld penetration, investigated circa 2006.

The *Laponia* was built to LR class in 1963 by A/B Götaverken; she was the first vessel constructed using the new conveyor method pioneered by the shipyard.

By the 1950s, the largest shipbuilder in terms of tonnage output was Götaverken. Having outgrown its Cityvarvet yard in central Gothenburg, a new, large and 'ultra-modern' yard was completed in 1963 at Arendal. Götaverken pioneered modular construction with a high level of automation, and the majority of shipbuilding work was completed under cover. Shown is the stern section of a bulk carrier, probably *Laponia;* already in place are the auxiliaries and engine room components.
*Reproduced by kind permission of The Motorship*

The *Myrina*, built in 1968 by Harland & Wolff, Belfast. Shown in January 1976 on the River Mersey, having broken her moorings during gales.

Daniel Keith Ludwig, a US shipowner, who pioneered the construction of supertankers in Japan by investing in the shipbuilding industry there.
*Reproduced by courtesy of Ludwig Cancer Research*

The Japanese-built tanker, *Universe Apollo*, built in 1958 by National Bulk Carriers Inc., Kure. She exceeded 100,000 dwt, making her the first of what came to be known as the supertankers.

The *Nissho Maru*, built by Sasebo Heavy Industries in 1962 for Idemitsu Kosan of Tokyo. At 132,334 dwt, *Nissho Maru* was the largest tanker in the world at that time and traded between Mina al-Bakr, Iraq and Tokuyama. She was broken up in 1978.

At 458.45 metres length overall, one of the largest supertankers ever built was *Seawise Giant* – shown here under her later name, *Jahre Viking*. Commissioned in 1979, she was too large to navigate the English Channel, let alone the Suez or Panama Canals. Near the end of her life she was used as a storage vessel, then was broken up in 2009.
*Reproduced by kind permission of Fotoflite*

A refinery at Maasvlakte 2 at Rotterdam, where a huge civil engineering project has been under way to construct an extension to the port on 2,000 hectares of reclaimed land; the first part of the project opened in May 2013.

The 1960 expansion of the Port of Rotterdam saw the creation of an industrialised area to the west known as Europoort. Rotterdam was the world's busiest port in terms of the volume of traffic handled until 2004, but the meteoric rise of Shanghai, Singapore and several others ports outstripped it. At the time of writing, Europoort, with an area of 10,500 ha, is still the third largest port in the world.

Container gantries at Felixstowe, UK.

Container handling at Southampton, UK.
Containers at Maasmond, Port of Rotterdam.

The *Ever Growth*, completed by the China Shipbuilding Corporation's Keelung yard in 1985.

The Port of Dalian, established in 1899, is the largest multipurpose port in North East China.

Shipping off Singapore in the 1980s.

The ongoing construction of LR's Southampton Global Technology Centre shown in April, 2013.

## Chapter 10 – The container revolution

Epic image:
Boxboat silhouette - Ambrose Greenway Collection

Boxcars were used to transport freight and livestock on railway and canal systems across the world. They can be seen as the forerunner of containerised cargo movement dating back to the early 19th century.
*Reproduced by kind permission of Collections of Maine Historical Society*

Malcom McLean, the father of the modern container, had the foresight to realise that the container would, through its integration with several modes of transport, introduce door-to-door shipment.

The converted T2 tanker *Maxton*, originally built in 1945 as *Black River,* was fitted in 1956 with a platform for carrying containers in order to trial McLean's novel idea, running between Port Newark and Houston; she retained her cargo tanks and so could still carry oil as well.

Container traffic has changed both the location and the structure of ports and terminals. Terminals are now located close to the open sea, often away from centres of population, with many deepwater berths, plus onshore space for container handling and transhipment to other ships or the road and rail networks. Gone are the vast dockside warehouses where goods would be stored until sold, sometimes remaining in storage there for years.

The SEABEE *Tillie Lykes* was launched by General Dynamics Quincy on 23 September 1972. She can carry 993 containers – but her interesting feature was the 2,000-ton capacity submersible stern elevator used for loading and unloading the 38 SEABEE barges she was also designed to carry. The barges are towed out to the ship and lifted by the elevator for stowing, the reverse happening at the destination port.

*BACAT 1*, the first of the Barge Aboard Catamaran (BACAT) vessels, launched in September 1973 and shown in the Pool of London. The BACAT used narrower British Waterways Board barges, loading 18 of them via a 400-ton elevator for carriage across the North Sea to European ports such as Rotterdam for unloading, then taken via the canal systems to central European destinations.

The LASH carrier *Rhine Forest* ex *Bilderdyk*, built for Holland America Line's Gulf of Mexico to Europe service which, in conjunction with Hapag-Lloyd A.G., was operated under the name Combi Line.

The 1983 built *Thorseggen* was of a novel design whereby a clever arrangement of cargo space and deck gear meant she could carry wood pulp for the paper mill on one voyage and milled newsprint reels on another.
*Reproduced by kind permission of Fotoflite*

*Mærsk Mc-Kinney Møller*, the lead ship of Maersk's Triple E–class, completed by Daewoo Shipbuilding and Marine Engineering (DSME), of South Korea in July 2013, she is the first of a class of 20 vessels each of 194,849 gt and capable of carrying 18,270 teu at a service speed of 23 knots.
*© Krijn Hamelink*

The container is a very strong steel box used to carry goods by sea, road, rail and air around the world. Containers give good service for many years before being decommissioned and scrapped, but a few go on to have second lives and are used in many interesting and inventive ways – not just as storage, but also as shelters, homes, works of art or even swimming pools. Images reproduced by kind permission of the following; Yin Xiuzhen, Urban Space Management (Container City) Ltd, Stefan Lemke for 25hours Hotels, LAND studio, Ravi Sidhu, Sunset Cargo, Martin Tenbones, Urban Space Management (Container City) Ltd and Urban Space Management (Container City) Ltd.

*Kooringa* was possibly one of the earliest cellular container vessels in the world, although her 'seatainers' as they were called, were smaller than the standard teu size. Built for service between Fremantle and Melbourne, she had two 71-ton moveable gantry cranes for handling the seatainers.

*American Lancer* was built by Sun Shipbuilding in 1968 for United States Lines. She was the first purpose-built, fully cellular containership to cross the Atlantic between the US and Europe.

Built in 1969 by Howaldtswerke-Deutsche Werft AG, Hamburg for the Overseas Container Consortium, *Encounter Bay* was regarded as the first of the second-generation containerships. With two steam turbines double-reduction-geared to a single propeller shaft, giving 32,000 shp and a speed of 21.5 knots, *Encounter Bay* was capable of carrying 1,578 teu, including 374 refrigerated units, between Europe and Australia. She was broken up in 1999 in China.

The third generation of containerships, capable of carrying in excess of 2,000 teu, swiftly followed and included Sea-Land's SL7s, the fastest ever cargo ships. Designed by J.J. Henry Co. and model tank tested at the Stevens Institute, the eight ships had graceful, sharp lines and were powered by General Electric steam turbines producing 120,000 shp to twin screws. Capable of more than 33 knots, the SL7s still hold the record for the fastest crossing by cargo ship of both the Atlantic and the Pacific oceans. *Sea-Land Exchange*, whose Atlantic crossing in 3 days, 11 hours and 24 minutes averaging 34.92 knots, was faster than either the *Queen Mary* or the *Normandie*, still (at the time of writing) holds the Atlantic record.
*Sea-Land McLean reproduced by kind permission of Fotoflite*

When container terminals are built or extended, their new container-handling equipment is usually constructed many thousands of miles away. It must then be transported, using the converted *Zhen Hua* 23, to its final destination.

The increasing size of containerships restricted the ports they could use. The answer lay in hubs, such as the Hamburg Süd Cartagena hub in Colombia. Large containerships unload at the hub, where their containers are transhipped to smaller feeder vessels for transportation to smaller ports.

*COSCO Indonesia* on the berth at the port of Tianjin.

Containership with containers being loaded; the guides and the marks for the containers are visible.

The 2010 built, 152,991 gt *French Explorer*-class containership *CMA CGM Amerigo Vespucci*, capable of carrying 13,830 teus including 800 refrigerated units.

China Shipping Container Line's *CSCL Globe* arrived at Felixstowe on 7 January 2015 on her maiden voyage. At the time she was the world's largest containership with a teu capacity of 19,100, and her MAN B&W engine, with an output of 69,720kW, was the largest in the world, measuring 17 metres in height. But within only a few weeks her teu record was broken, by *MSC Oscar,* with a teu capacity of 19,224 units. In March 2015, MOL announced a series of four new 20,150-teu containerships to be built by Samsung Heavy Industries, Korea, to LR class.

Christened on 8 January 2015, *MSC Oscar,* with a teu capacity of 19,224 units, became the largest containership in the world. The 197,362 dwt vessel was built by Daewoo Shipbuilding and Marine engineering (DSME), South Korea, for the Mediterranean Shipping Company (MSC).

The ongoing construction of LR's Southampton Global Technology Centre shown in May, 2013.

## Chapter 11 – The decline and revival of the large passenger ship

Epic image:
*Costa Fascinosa*, Venice – Barbara Jones

The passenger liner *United States* completed in 1952 for United States Lines is still the fastest passenger liner ever built, making an average of 35.5 knots on her maiden voyage. In order that she could be rapidly converted to a troopship, she featured all metal construction and internal design – the exceptions being her piano and the butcher's blocks.

Nippon Yusen Kaisha's *Hikawa Maru,* built in 1930 by Yokohama Dock Co., ran a service from Kobe and Yokohama to Vancouver and Seattle, with occasional calls at Honolulu. The ship is now preserved as a museum at Yokohama.

Cunard Line's *Queen Mary,* completed to LR class in 1936, held the Atlantic speed record until the maiden voyage of the *United States.* Designed to carry 2,139 passengers and 1,100 crew, she retired from service in 1967 and is now permanently moored at Long Beach, California.

Completed to LR class in 1961 and put into service as a flagship for the new P&O–Orient Line, *Canberra* was designed with many special features including a bulbous bow and bow thrusters. Features for passengers included a large forward-facing observation lounge, a sprung dance floor and a Teenager's Room with juke box. She remained in service until 1997.

Completed in 1965 by Ansaldo S.p.A., Genoa, *Michelangelo's* striking feature was her two latticework funnels topped by large smoke deflectors, designed by Professor Mortarino of the Turin Polytechnic. The funnels were designed to allow the wind to pass through, keeping the smoke off the rear decks.

Samuel Cunard
*Reproduced by kind permission of Cunard*

*The Record Breakers* by John S Smith
Cunard's *Britannia*; the *United States*; and the first *Mauretania*.

Greek Line's *Arkadia* was built to LR class in 1931 as the 22,424 grt *Monarch of Bermuda*. Used as a troopship during the war, she was refitted as an emigrant ship and then purchased by the Greek Line in 1958 for service between Montreal and Europe, with regular cruising voyages during the winter months.

Typical of the design features of the cruise ships built in the 1970s, *Song of Norway* had the appearance of a stylish yacht, with a modern version of the clipper bow and a forward observation lounge.

The interwar period was the age of elegance and speed in passenger liners, whose primary purpose was to take passengers from one place to another, each company trying to outdo the other with lavish internal design and decoration, and the speed and comfort, of their luxurious liners. Enhanced by artworks from well-known artists of the day, the first-class areas were especially sumptuous. Post war, the liners' design became more streamlined but they were rapidly replaced by the airliner as the swiftest mode of travel. Reconfigured for cruising, many of these great ships lasted for a number of years. Modern cruise liners are designed not so much for speed as for passenger comfort and entertainment, with stunning atria, works of art and luxurious accommodation.

Britannia Restaurant on board Cunard Line's *Queen Mary 2*.

The *Queen Elizabeth's* interior panels and works of art were designed and executed by many of the leading artists of the day, including Margot Gilbert, Dame Laura Knight RA, Philip Connard RA, Kenneth D Shoesmith, Jan Tuta and James Woodford.

Carnival's distinctive whale-tail-shaped funnel, first used for *Tropicale* launched in 1980.

The luxurious *Radisson Diamond*, the first SWATH (Small Waterplane Area Twin Hull) vessel to be built for commercial passenger use, is now named *China Star*. Her operators, China Cruises Company Ltd, use her to provide luxury cruises for the growing Chinese cruise market.

The sculptures on board *Queen Victoria* were designed by John McKenna ARBS.

Nippon Yusen Kaisha (NYK) phased out their passenger services after Second World War but re-established this part of their operation with *Crystal Harmony*, launched in 1989 for Crystal Cruises. Renamed *Asuka II* in 2006 and sailing under the NYK brand, she now offers cruises out of Yokohama.

CGT's (French Line) *France*, completed by Chantiers de l'Atlantique, St Nazaire, in 1962 was designed for both passenger travel and cruising. All materials used in the building of the vessel were non-combustible. CGT used her distinctive funnels as a trademark in advertising and marketing, and even ashtrays were made in the distinctive funnel shape.

The luxurious interior of the *Berengaria*, originally built as the *Imperator* for the Hamburg–America Line in 1912.

Italia Line's quadruple-screw *Rex* won the Blue Riband in 1933, a year after her completion by Ansaldo Società Anonima, Sestri, Ponante.

One of the most stylish and elegant liners ever built, French Line's *Normandie* heralded a new age of art deco elegance on passenger liners, her bow-on silhouette so striking as to be used in the company's marketing. She cost $60,000,000 to build, and had many striking features inside and out. Her massive funnels were 160 feet in circumference with the foremost a towering 145 feet high. Her main dining room was three decks high and could seat 1,000 passengers, while her garage – common on ships of the time, when rich passengers would take their cars with them – could hold 100 cars.

Built in 1971 as *Island Venture* by Thyssen Nordseewerke GmbH, Emden, the 20,216 gt cruise ship *Discovery* had a long life under a variety of names until she went to the breakers in December 2014. As *Island Princess*, she and her sister vessel *Pacific Princess* found fame when featured in the popular American TV series *The Love Boat*. Her last operators, Voyages of Discovery, pioneered small ship cruising, offering their passengers the opportunity of exploring smaller ports of call not found on the usual cruise itinerary; for example, *Discovery* was the only non-Ecuadorian ship allowed to call at the Galapagos Islands.

*Leviathan* by John Stewart
*Leviathan* was built by Blohm & Voss, Hamburg, as *Vaterland* for Hamburg–America Line, and at the time was the largest ship in the world. Captured in New York during First World War she became United States Lines' *Leviathan*.

*Maasdam & Queen Mary* at Southampton by Hartley Crossley
Holland America Line's *Maasdam*, built by Wilton Fyenoord, Schiedam, entered service in 1952. She carried 854 tourist class passengers and just 39 first, and was also used for cruises.

*Themistocles* by John Charles Allcot, OBE, FRAS
Aberdeen Line's *Themistocles*, built in 1911 for their Australian service, had an ingenious form of ventilation that allowed fresh air to flow through the ship.

Matson Lines' *Matsonia*, ex-*Malolo*, was described in 1937 as 'one of the smartest, most beautifully appointed vessels afloat.' Her accommodation was fully air-conditioned for her scheduled voyages between San Francisco, Los Angeles and Honolulu.

The fourth of P&O Line's *Strath*-class of liners, *Stratheden* was completed by Vickers-Armstrongs Ltd in 1938.

*Allure of the Seas*, completed by STX Europe's Turku yard in 2010, is one of Royal Caribbean Line's *Oasis* class, the largest cruise ships ever built. Fitted with telescopic funnels to allow the ships to pass under low bridges, the vessels have 2,700 rooms spanning 16 decks, accommodating over 6,000 passengers.

Carnival Cruise Line's cruise ship *Carnival Vista* under construction at Fincantieri S.p.A. The vessel's specifications include two ABB Azipod XO diesel-electric units for propulsion giving a service speed of 23 knots. Her capacity is 3,936 passengers, and she has many of Carnival's 'FunShip' features, including the first IMAX cinema at sea.
*Reproduced by courtesy of Fincantieri S.p.A.*


Cunard Line's *Queen Mary 2*, launched at Chantiers de l'Atlantique, St Nazaire, in 2003, shown on her maiden visit to Sydney, Australia. The *Queen Mary 2* has been designed with reference to the elegance, majesty and splendour of the old passenger liners.

*Queen Mary 2*, Cunard Line's flagship, shown under construction, is designed to cross the North Atlantic at the height of winter. She is powered by an integrated propulsion system: four diesel engines and two gas turbines producing the power for her four electric propulsion pods.

The ongoing construction of LR's Southampton Global Technology Centre shown in September, 2013.

## Chapter 12 – The search for cleaner fuel at sea

Epic image:
Whale tail, Juneau, Alaska – Gareth Jones

Conversion for the first gas-powered marine installation was completed under LR survey in 1947 on board the Royal Navy motor gunboat *MGB 2009*.

The modern gas turbine takes up very little room compared to a conventional engine, making it an economic alternative for cruise lines where increased passenger space has a direct economic impact. Shown is the MT30, derived from Rolls-Royce aero engine technology for naval purposes. It is the world's most powerful in-service marine gas turbine, producing 36 to 40 mW.
*Reproduced by kind permission of Rolls-Royce plc*

HMS *Dreadnought* (S101) was the UK's first nuclear-powered submarine, built by Vickers-Armstrongs at Barrow and in service from 1960 until 1980.

The USS *Enterprise* (CVN-65) was the world's first nuclear-powered aircraft carrier and the longest naval vessel in the world. Built for the US Navy by Newport News Shipbuilding and Drydock Company in 1959, she was deactivated in 2012 and was decommissioned on 3 February 2017.

*Lenin*, the world's first nuclear-powered merchant ship, was launched in 1957 by Baltic Shipbuilding and Engineering Works, Leningrad. With her nuclear power units removed, she is now a museum ship at Murmansk; the quayside alongside is a popular destination for newly married couples, who attach a padlock to the railings to signify their love before throwing the key into the harbour.

Murmansk Shipping Company's nuclear powered icebreaking LASH carrier, *Sevmorput,* completed in 1988 by Zaliv Shipyard, Kerch, Ukraine.

The nuclear cargo ship *Savannah*, built by the New York Shipbuilding Corporation in 1959, shown en route to the 1962 World Fair in Seattle.

Nuclear cargo ship *Savannah*'s pressurised water reactor, designed and built by the Babcock and Wilcox Company. The square-shaped nuclear fuel elements are shown in the central region of the reactor vessel, with control rods extending up through them.

Rudolf Diesel's signature.

Rudolf Diesel

Single-cylinder diesel engine prototype.

The SkySails system uses enormous kites to tow ships. SkySails claims that its kites produce up to 25 times more energy per square metre than ordinary sails.

A series of revolutionary LNG and dual-fuelled ferries were approved and classed by LR in 2014. This is a computer-generated image of the LR classed *Texelstroom*. Completed in 2016, the double-ended ferry is multi-fuelled, with an advanced energy management system – predominantly dual-fuel LNG with diesel, supported by electric batteries and 700m² of solar panels.
*Reproduced by kind permission of TESO*

Opened in May 2013, the new LNG facility on Jurong Island is the first of its kind for Singapore.
*Reproduced by kind permission of Petrochemical Corporation of Singapore (Private) Limited*

The *Viking Grace*, an LNG-powered passenger ship built by STX Finland in 2013, is one of the most environmentally friendly in the world.
*Reproduced by kind permission of Viking Line*

Lloyd's Register LNG Bunkering Infrastructure Survey 2014.

The ongoing construction of LR's Southampton Global Technology Centre shown in November, 2013.

**Chapter 13 – Technology and the seafarer**
Epic image:
Vehicle carrier *Courage* at night - Maciej Wolaniecki

Automation helped lower costs by reducing the amount of crew accommodation required; the *Kinkasan Maru* of 1961 needed accommodation for 43 crew, whereas in 1965 the *Tokyo Maru* accommodated only 29.
*Tokyo Maru reproduced by kind permission of Fotoflite*

Bridge on a merchant ship pre-1950; the pilot gives a helm order and the ship's officer works the engine telegraph.

An older style bridge aboard *Saga Rose*.

The first communications satellite, known as Telstar, was launched in 1962 from Cape Canaveral.

Satellite internet connections are both common and essential for research vessels. The Schmidt Ocean Institute has upgraded the satellite system aboard the research survey vessel *Falkor*, completed in 1981. The vessel now has two prominent white domes housing satellite antennas that offer improved internet access and video streaming capabilities to the benefit of everyone working aboard.
*Reproduced by kind permission of Mark Schrope*

The bridge of the platform supply ship *Stril Luna*, delivered in 2014 by the Astilleros Gondán shipyard in Spain to its owner, Simon Møkster Shipping. It contains the first unified bridge from Rolls-Royce, which resulted from a long development of integrated ship systems plus three years' design and human factor laboratory work.
*Reproduced by kind permission of Rolls-Royce plc*

In 1980, the supertanker *Esso Languedoc* was struck by a rogue wave that washed across the deck from the stern. The mast, seen right in the photo, stands 25 metres above mean sea level. This remarkable photograph of her near Durban, South Africa, was captured by the first mate, Philippe Lijour.
*Reproduced by kind permission of Philippe Lijour*

International Code of Signals, flag codes.

ECDIS use is now widespread, the system utilising resources such as AIS and radar for navigational application, displaying routes as electronic navigational charts like this one of Falmouth Harbour, UK.
*©Crown Copyright/Euronav*

*Marconi Transmitting the First Radio Signals to Newfoundland, 1901*, by Barbara Jones
*Reproduced by kind permission of Liss Llewellyn Fine Art*

The chemical tanker *Dutch Spirit*, completed in 1996 for Dutch operator Broere Shipping BV, was equipped with a Racal-Decca MIRANS 4600 integrated bridge system, becoming the world's first ship to operate legally with electronic charts as its main navigation system.

Cross-section showing crew accommodation aboard the *Queen Mary* at numbers 88, 107, 128 and 157.

Accommodation plans for *Blackheath*, built by Caledon Shipbuilding & Engineering Co. in 1936 for Watts, Watts & Co. The company added three such B class ships to its fleet – the *Blackheath, Beckenham* and *Beaconsfield* – with the officers sharing common areas in the accommodation for the first time. Edmund Watts had great interest in such improvements, and read a paper before INA in April 1945 entitled 'Crew accommodation in tramp-ships'.

Cover page of LR's *Human Focus*, issue 1.

Cartoon from the first issue of *Alert!*
*Reproduced by kind permission of the Nautical Institute*

Crew on watch on the bridge of the Yang Ming container vessel *YM Upsurgence*.

The ongoing construction of LR's Southampton Global Technology Centre shown in January, 2014.

## Chapter 14 – Regulation and technology

Epic image:
Trinity House *Alert* - Maciej Wolaniecki

On 18 March 1967, the *Torrey Canyon* struck rocks between the Isles of Scilly and Land's End, on mainland UK and 120,000 tonnes of oil were spilled. The disaster was the first major spill involving a supertanker, and it led to a number of changes to international regulations.
*©Crown Copyright/MOD*

The IMO's Marine Environment Protection Committee meets for its 66th session, from 31 March to 4 April 2014, at the IMO Headquarters in London.
*Reproduced by kind permission of the IMO*

Barrels on the quayside at Wapping, London. Historically the tun or 'tunne' was an English unit of liquid volume and took the form of a very large barrel, from which ton came to be used as a description of the cubic capacity of a ship, indicating how many tuns could be stowed. Originally, the tun was defined as 252 wine gallons, it was also used for measuring honey and oil. The wine barrel was half a wine hogshead or an eighth of a tun, so the contents of eight of the barrels shown on the quayside would fit into one tun.
*Reproduced by kind permission of Bishopsgate Library, Bishopsgate Foundation and Institute*

Revised International Safety Management (ISM) Code 2002.
*Reproduced by kind permission of the IMO*

The *Herald of Free Enterprise*, shown in Eastern Docks, Dover, UK in 1984. The ro-ro ferry capsized moments after departing from the port of Zeebrugge, Belgium, on 6 March, 1987 on her return journey to Dover.

On 16 March 1978, the VLCC *Amoco Cadiz* ran aground on Portsall Rocks, off the coast of Brittany, France. She split into three and sank, resulting in the largest oil spill of its kind to that date and leading to the incorporation of new measures in the 1979 SOLAS amendments.
*Reproduced by kind permission of the US National Oceanographic and Atmospheric Administration*

ClassNK - *Port State Control Annual Report*, August 2014.
*Reproduced by kind permission of ClassNK*

On 12 December 1999, the oil tanker *Erika* broke in two and sank, releasing thousands of tons of oil into the sea off the coast of Brittany. The sinking of the *Erika* and the *Prestige* tankers, 1999 and in 2002 respectively, triggered new EU legislation with regard to maritime transport.
*Reproduced by kind permission of the French Navy*

A newly completed ship undergoing trials.

*Eugeniusz Kwiatkowski*, a REM 120-type multi-purpose, heavy and oversized cargoes, container and dangerous cargo carrying vessel launched by Stocznia Pólnocna, the Northern shipyard of the Remontowa Group, Poland. The ship is named for the innovative and visionary Polish engineer and politician who pioneered the construction of Gdynia port prior to Second World War.

The ongoing construction of LR's Southampton Global Technology Centre shown in March, 2014.

## Chapter 15 – The classification societies and the application of science and technology

Epic image:
LR surveyor at work - Maciej Wolaniecki

LR's Chairman from 1946 to 1957, Sir Ronald Garrett travelled extensively around the world meeting staff and clients.

A tanker bunkering at Aden.

Badge from the Conference on Classification Societies held in 1959.

IACS has 12 member societies and makes a unique contribution to maritime safety and regulation through technical support, compliance verification and research and development.

Sir Kenneth Pelly, LR's Chairman from 1957 until 1963, made personal contact with many members of staff around the world and oversaw the establishment of the Greek, Finnish and Indian National Committees, providing LR with a further communication channel with the industries that it serves.

Professor John Carlton trained as a mechanical engineer and mathematician. After work in the Royal Naval Scientific Service and as a propeller designer and research engineer, he joined LR in 1975, working in the Technical Investigations, Advanced Engineering, and Performance Technology Departments. He was LR's Global Head of Marine Technology from 2003 until 2009. In 2011, Professor Carlton became the 109th President of the IMarEST.

Strain gauging a model steel crankshaft to confirm the measurement of computer-predicted analyses at Crawley research laboratory circa 1979.

In 1947, LR's Engineering Investigations Department (EID) was formed; this was later renamed the Technical Investigations Department (TID). Combining a staff of engineers and scientists with a variety of practical and theoretical expertise, the EID complemented research activities, helping to resolve problems and absorb lessons learnt from failures at sea to further improve the *Rules*, something the TID continues to do today.

A special testing machine designed and built by LR's Materials Laboratory in Croydon for its research programme into the fatigue performance of Fibre Reinforced Polymer (FRP) composite materials.

In 1987, LR's Voyage Data Recorder was a first in the industry. The marine 'black box' recorder continuously measured collected and stored information from data sources around the ship.

The 212,000 dwt *John A McCone*, shown here at Europoort in 1976, was the first of a new generation of giant oil tankers designed using the new FEA techniques.
*Reproduced by kind permission of Arthur P. Cooley/ John Curdy Collection*

In 2014 the first in a series of a ground-breaking new Moss LNG carrier design was delivered to LR class by Mitsubishi Heavy Industries (MHI). The 'Sayaendo' design was the culmination of several years of development by MHI based on the patented Integrated Hull Structure (IHS) concept licensed by Aker Arctic Technology Inc.
It features four Moss spherical tanks protected by a peapod-shaped continuous cover integrated with the ship's hull enabling a reduction in weight. The 155,000 $m^3$ ships boast greater structural efficiency and an approximate 20-25 per cent reduction in fuel consumption per cargo unit over a 147,000 $m^3$ conventional carrier.
*Reproduced by kind permission of MHI*

A finite element model of the 'Sayaendo' design used for strength and fatigue assessment.
*Reproduced by kind permission of MHI*

LR, in association with BP Shipping Ltd and the Korean shipbuilder Samsung Heavy Industries, carried out a long-term strain monitoring exercise on board the 151,401 dwt crude oil tanker *British Hunter*, built in 1997.

The 26,264 dwt bulk carrier *Lake Carling*, originally built in 1993 as *Ziemia Cieszynska*, sustained a six-metre fracture in her hull while bound from Quebec to Trinidad, loaded with a cargo of iron pellets.
*Reproduced by kind permission of Transport Safety Board of Canada*

LR has commissioned crack arrest research at TWI; the left image is a test conducted at -20°C showing fracture without arrest in the plate material; the right image shows the same test having been conducted at -10°C and the fracture arresting in the plate material.

A bulk carrier, shown bow on, under construction at the New Xingang Shipyard, Tianjin, China, in May 2011. The vessel was the first ship to be built in the new facilities and construction of the dry dock was undertaken at the same time.

Research was carried out at LR's purpose-built research laboratory at Crawley; opening in the 1950s, it demonstrated the importance that LR has always placed on research.

In the 1990s, LR expanded its knowledge by studying marine exhaust emissions in a transient operational mode.

In 2012, LR established the Singapore Global Technology Centre (GTC). Capabilities and resources of the GTC Singapore have steadily scaled upwards with investment in the facility expected to reach US$35 million by 2017. The centre has now expanded to 40 employees and plans to reach 50 employees by the end of 2015. By 2017, up to 150 full-time engineers, researchers and doctoral students will be jointly employed and working together with industry on projects of mutual interest through the GTC Singapore. A joint laboratory with A*STAR's Institute of High Performance Computing (IHPC) was opened by GTC Singapore on 22 April, 2013, to continue running collaborative projects in the marine, energy and offshore sectors.

*Prelude*, Shell's floating liquefied natural gas (FLNG) facility, at nearly 500 metres in length, will be the world's largest floating facility. It will be installed off the northwest coast of Australia in the Browse basin, and will not be dry-docked for the first 25 years of its expected 50-year operational life.
*Reproduced by kind permission of Photographic Services/Shell International Limited*

The ongoing construction of LR's Southampton Global Technology Centre shown in June, 2014.

## Chapter 16 – The impact of shipping technology since 1945

Epic image:
Moss cargo tanks - Jack du Bois

Night loading at the Euromax Terminal, Rotterdam.

Bulk carriers are designed specifically to transport unpackaged bulk cargo like coal, cement, grain and ore in cargo holds. The vessel type has grown both in size and in sophistication, including specialised designs to facilitate unloading at different ports.

As containership sizes continue to expand, to create economies of scale, their owners and managers are forever seeking sleeker and more streamlined ways to load, stack and carry their boxes. A major research project completed by LR in 2013 discovered a unique way to improve the way containers are handled and carried. It means that in future, ultra-large containerships (ULCS) using the new method could potentially load up to 19 per cent more cargo weight.

Constance Tipper was a British metallurgist and crystallographer.

On 16 January 1943, the all-welded T2 type tanker *Schenectady* was lying alongside at the shipyard of the Kaiser Company, Portland, Oregon, after returning from her sea trials. Celebrations over the completion of the yard's first tanker were cut short by a loud noise as *Schenectady* cracked across its deck and down both sides.

The refrigerated tanker *Orange Blossom*, a 15,108 dwt reefer launched to LR class in 1984 for registered owners Atlantic Reefer Corporation Inc., was the first purpose-built fruit juice carrier.

After 1907, the United Fruit Company's fleet of fast reefer vessels were painted white to deflect the tropical sunlight and keep bananas cooler, becoming known as the 'Great White Fleet'.

Ports and terminals never close; loading and unloading goes on around the clock.

Nordic Yards' drydock facilities at Rostock-Warnemünde on a calm winter's day in 2014.

The new London Gateway megaport will provide 2,700 metres of quay with an annual capacity of 3.5 million teus.
*Reproduced by kind permission of DP World, London Gateway*

LR's Southampton Global Technology Centre shown in February, 2015.

## Chapter 17 – The future

Epic image:
Karl G. Jansky Very Large Array (VLA) radio astronomy observatory, New Mexico, USA - Gerard Gaal

LR was involved with the building of Allseas' giant heavy-lift and pipe-laying vessel from the original planning stages until her final completion in early 2015. The *Pioneering Spirit* is the world's largest vessel; many of her major and complex structures were designed and reviewed using FEA calculations. LR's London and Rotterdam teams worked closely with Allseas Engineering in the Netherlands and at the builder DSME's shipyard in Okpo, South Korea.

Map showing some 40 per cent of the world's LNG terminals (ones that DNV had worked with by 2011). DNV explain that although the world is scattered with LNG terminals for both export and import, very few, if any, of these terminals will allow individual ships to bunker at the terminal premises. So a dedicated bunkering infrastructure is needed between the LNG terminals and the maritime consumers.
*Reproduced by kind permission of DNV GL*

As regards new engines, with the order book growing, MAN Diesel & Turbo's ME-GI series, low-speed, two-stroke diesel cycle engines, operating on both high-pressure natural gas and conventional fuel oils, will undoubtedly increase the uptake of liquefied natural gas (LNG) as a bunker fuel both for environmentally sensitive areas and, with reducing global sulphur limits, for worldwide trades.
*Reproduced by kind permission of MAN*

Caledonian Maritime Assets Ltd's *Hallaig* and *Lochinvar* are the world's first sea-going ro-ro vehicle and passenger diesel-electric hybrid ferries. Built in Scotland, *Hallaig* was completed to LR class in 2013. The ferries, designed for use on many of the short-crossing routes around the Clyde and Hebrides, use innovative new 'green' technology including two lithium-ion battery banks totalling 750kWh which supply a minimum of 20 per cent of the energy consumed on board and reduce fuel and $CO_2$ consumption by at least 20 per cent. The battery banks are charged overnight from a shore-based electricity supply.
*Reproduced by kind permission of Caledonian Maritime Assets Limited*

NYK Line's 6,200 capacity car carrier *Auriga Leader* is the first ship in the world to be partially propelled by solar power. From December 2008, shipboard tests to determine the power generation and endurance of the photo-voltaic panels showed the difficulties of providing a stable power supply. In 2011, an innovative hybrid power supply system was installed on the vessel, which was also fitted with a ballast-water management system and adapted to use low-sulphur fuel to further strengthen environmental measures.

For the last three years, Swiss-based company THiiiNK has been developing the Flettner rotor, a large rotating cylinder that harnesses wind power via the 'Magnus effect', a concept first developed in the 1920s but not yet effectively commercialised. The THiiiNK team, along with industry partners including LR, plans to trial the concept on a long-range (LR2) or Suezmax tanker early in 2015. On a projected voyage from the Cabot Strait (off the coast of eastern Canada) to the English Channel, the effect of Flettner rotors is calculated to reduce a vessel's main engine output by around 28 per cent.

Froude's testing tank, circa 1872.
*©IWM (HU82582)*

The new model testing tank under construction at the University of Southampton. Testing tanks are usually 'christened' before commissioning with a few drops of water taken from Froude's first tank.

Rolls-Royce design concept of an unmanned LNG-fuelled ship.
*Reproduced by kind permission of Rolls-Royce plc*

Researchers at DNV GL have developed *ReVolt*, a concept vessel that is greener, smarter and safer than conventionally fuelled and operated vessels. Autonomous and highly efficient it is powered by a 3,000 kWh battery, and without the need for crew facilities, has an increased loading capacity, low operating and maintenance costs. Compared to a diesel-run ship *ReVolt* could save up to 34 million USD during its estimated 30-year life-time.
*Reproduced by kind permission of Toftenes Multivisjon©DNV GL*

Tom Boardley, LR's Marine Director, at the Singapore launch of *Global Marine Trends 2030*. A comprehensive report issued in London and Singapore by the team from QinetiQ, LR and Strathclyde University, it predicts growth in the commercial shipping, naval and offshore energy sectors, and strives to provide a framework for thinking about possible futures and their implications.

Whipping and springing tests, WILS II containership.

Comparison of springing and whipping responses of model tests with predicted non-linear hydro-elastic analyses on a 10,000-teu WILS II containership hydro-model. The phenomena can be critical for the design and operation of large containerships due to the size of deck openings. The model scale measurements of the 'Wave Induced Loads on Ships Joint Industry Project-II' were undertaken at Maritime & Ocean Engineering Research Institute (MOERI), Daejeon, South Korea, in 2009 and 2010.

In 2014 LR moved 400 members of its marine team into a new purpose-built facility on the University of Southampton's Boldrewood campus, establishing a new Global Technology Centre (GTC). Grimshaw Architects LLP designed the new development with structural engineers Buro Happold Limited.

Members of LR's Technical Committee admire the original design features of the new Southampton GTC from its modern spiral design staircase. Wates Construction undertook significant ground preparation works to accommodate two buildings – a high-quality commercial office building of approximately 100,000 square feet over five floors, and the University's Faculty of Engineering, with approximately 65,000 square feet over five floors.

Completed in 2002-3, to LR class, the 106,208 dwt ice-breaking Aframax crude oil tanker *Tempera* and her sister ship *Mastera*, were the first double-acting tankers. They go ahead in open waters and astern in ice conditions, and this enables them to operate all year round from the Primorsk oil terminal in Russia to the Neste oil refineries in Finland.

A future bridge operation concept created by Rolls-Royce under Finnish Metals and Engineering Competence Cluster (FIMECC) user experience and usability program (UXUS). This concept for tug vessels was envisioned in 2012–14 together with VTT Technical Research Centre of Finland.
*Reproduced by kind permission of Rolls-Royce plc*

US-based TOTE, Inc. is building the world's first LNG-powered containerships; the first two Marlin-class vessels are due for completion in late 2015 and early 2016, built by General Dynamics NASSCO in San Diego, US. The vessels will be dual-fuelled and able to operate up to 4,000 nautical miles on LNG, with the capability to switch to bunker fuel when necessary.

A virtual-reality prototype, which simulates 360-degree views from a vessel's bridge has been set up by Rolls-Royce plc's Blue Ocean development team in Norway. Eventually, the global manufacturer of engines and turbines predicts that captains ashore will use similar control centres to command hundreds of crewless ships.

At one of the busiest ports in Europe, the Port Authority of Antwerp is consolidating its operations into a single, stunning building, designed by Zaha Hadid Architects to symbolise Antwerp's status as a world port and completed in September, 2016.
*Reproduced by kind permission of Zaha Hadid Architects*

Architectural drawings by Masters students show a FlexHubDock, envisioning the city of Barcelona in around 2050 with the port area as a new hub for commerce, logistics, people and the city. Rethinking the development as whole new 'social layer', the FlexHubDock shows 'how port and city can coexist in harmony'.

Unmanned ships concept.
*Reproduced by kind permission of Rolls-Royce plc.*

# Glossary and abbreviations

**ABS – American Bureau of Shipping**
United States classification society, founded in 1862.

**Aframax**
A bulk carrier, typically of 75,000 to 120,000 dwt.

**AIS – Automatic Identification System**
An automatic shipping tracking system that uses data between nearby ships to relay a ship's position.

**BACAT – Barge aboard catamaran**
See also LASH.

**Ballast**
Ballast is carried instead of cargo in order to stabilise an empty vessel. Time spent not carrying cargo is time 'in ballast'.

**BC – The British Corporation for the Survey and Registry of Shipping**
Formed in 1890 by a group of independent-minded Scottish shipowners and shipbuilders on the River Clyde, BC was intent on providing owners and builders with choices during the load line debate

**bhp – brake horsepower**
Brake horsepower is the actual horsepower put out by an engine.

**bm – builder's measurement**
A method formerly used for measuring ships for tonnage, and by shipbuilders to charge for construction, calculated by taking the vessel's length between perpendiculars, in feet, deducting three fifths of the beam (in feet), multiplying the remainder by the whole beam (in feet), and the product again by half the beam and dividing this last product by 94

**Bollard pull**
The amount of force a tug is capable of applying to a tow under certain conditions

**Bulbous bow**
The bulbous bow eliminates the bow wave and reduces resistance, which optimises fuel efficiency when loaded to a certain draught and travelling at a certain speed

**Bulker**
A bulk carrier, bulk freighter, or bulker is a merchant ship specially designed to transport unpackaged bulk cargo, such as grains, coal, ore, and cement in its cargo holds.

**Bunkering**
The act or process of supplying a ship with fuel. Bunker fuel is technically any type of fuel used aboard ships.

**BV – Bureau Veritas**
French classification society, founded in 1828

**Capesize**
A ship of 100,000 to 180,000 tonnes dwt. Too big for the Panama or Suez Canals, Capesize vessels voyage via Cape Horn or the Cape of Good Hope.

**CCS – China Classification Society**
Chinese classification society, founded in 1956.

**Cell**
The compartment on a containership that the teu is slotted in.

**Certification**
The process of evaluation that results in a written statement, usually by a third party, that a system or component complies with its specified requirements and is acceptable for operational use.

**CFD – Computational Fluid Dynamics**
A branch of fluid mechanics that uses numerical methods and algorithms to solve and analyse problems that involve fluid flows.

**Classification**
The development, implementation and maintenance of standards (*Rules*) for the design, construction and operation of ships and offshore units. Compliance with these standards ensures assignment and maintenance of class.

**Classification society**
A classification society is a non-governmental organisation that establishes and maintains technical standards for the construction and operation of ships and offshore structures.

**ClassNK**
Japanese classification society, also known as Nippon Kaiji Kyokai (NK), which was founded in 1899 as Teikoku Kaiji Kyokai

**Conference**
Two or more shipping lines operating a service in the same geographical area for agreed freight rates. Sometimes referred to as freight or liner conferences or consortium.

**COSCO – China Ocean Shipping Company**
Founded in April 1961, COSCO is a shipping and logistics supplier company.

**CRS – Croatian Register of Shipping**
Croatian classification society, founded in 1949.

**CSR – Common Structural Rules**
The IACS CSR for tankers and bulk carriers aim to achieve the goals of more robust and safer ships.

**Displacement tonnage**
Displacement tonnage is the immersed weight displaced in water, based upon Archimedes' Principle.

**DNV – Det Norske Veritas**
Norwegian classification society, founded in 1864. In September 2013, DNV merged with GL to become DNV GL.

**DNV GL**
Classification society formed in 2013 by the merger of DNV and GL.

**DPS – Dynamic Positioning System**
An automated system that maintains a vessel's position and heading using her propellers and thrusters.

**dwt – deadweight**
Deadweight specifies the weight in tonnes (1,000 kg) of cargo, stores, fuel, passengers and crew carried by a vessel, expressed in tonnes. It is often used to specify the maximum permissible load.

**EC – European Community**
Precursor to the European Union (EU) formed in 1957 as the European Economic Community (EEC), and incorporated and renamed European Community (EC) in 1993 and European Union (EU) in 2009.

**ECDIS – Electronic Chart Display and Information System**
An alternative to traditional paper charts, the Electronic Chart Display and Information System is a digitised mapping program that operates in co-ordination with IMO rulings.

**EU – European Union (EU)**
The Treaty of Lisbon 2009 saw the foundation of an economic and monetary union and the renaming of the European Community (EC) to the European Union (EU).

**FEA – Finite Element Analysis**
A mathematical method of finding approximate solutions to boundary value problems concerning partial differential equations.

**Feet tenths**
Tenth of a foot divided into tenths usually to one or two decimal places and used in shipbuilding, offshore work and by engineers, surveyors, builders, architects and land surveyors.

**Flag state**
A sea-going vessel is subject to the maritime regulations of its country of registration, or flag state, in respect of manning scales, safety standards and consular representation abroad.

**FLNG – Floating Liquefied Natural Gas facility**
FLNG refers to water-based LNG operations employing technologies; designed to enable development of offshore natural gas resources floating above an offshore natural gas field, the FLNG facility will produce, liquefy, store and transfer LNG at sea before carriers ship it directly to market.

**FOI – Floating Offshore Installation**
Relates to any floating installation, regardless of its capability.

**FSO – Floating Storage and Offloading unit**
Floating production unit, which stores oil or gas as it is extracted from the seabed before delivering to export.

**GDP – Gross Domestic Product**
The market value of all final goods and services from a nation in a given year, which is calculated as the population times the market value of the goods and services produced per person in the country.

**GL – Germanischer Lloyd**
German classification society, founded in 1867. In September 2013, GL merged with DNV to become DNV GL.

**GPS – Global Positioning System**
A worldwide navigation system that allows users to determine their location using satellites.

**grt – gross registered tons**
Gross registered tons is, broadly, the internal capacity of a ship available for the cargo, passengers, crew and machinery spaces measured in cubic feet, divided by 100, expressed as gross registered tons. Therefore, 100 cubic feet equals one gross ton. Gross registered tonnage was replaced by gross tonnage for most flag states under the International Convention on Tonnage Measurement of Ships, adopted by IMO on 23 June 1969 and entering into force 18 July 1982.

**gt – gross tonnage**
Gross tonnage is a function of the moulded volume of all enclosed spaces of the ship. It forms the basis on which manning rules and safety regulations are applied and registration fees determined. Gross tonnage is determined from a formula using the total enclosed volume of the ship, and has no units.

**GTC – Global Technology Centre**
LR's new Global Technology Centre at the University of Southampton, completed in 2014.

**ha – hectares**
Usually a unit of measurement that refers to land and based on 100 acres, or 10,000 square metres.

**Handymax**
A bulk carrier, typically between 35,000 to 55,000 dwt.

**HEIC – Honourable East India Company**
One of the world's oldest maritime trading companies, its origins date back to 1600 when it was incorporated by Royal Charter of Queen Elizabeth I.

**hp – horsepower**
Horsepower is a unit of measurement of power representing the rate at which work is done. It was first adopted in the late eighteenth century by the engineer James Watt for comparing the output of steam engines with the power of draft horses.

**Human Factors**
Human factors involves the study of all aspects of the way humans relate to the world around them, with the aim of improving operational performance, safety, through-life costs and/or adoption through improvement in the experience of the end user.

**IACS – International Association of Classification Societies Ltd**
A membership organisation, formed in 1968, which contributes to maritime safety and regulation through technical support, compliance verification, and research and development. More than 90 per cent of the world's cargo-carrying tonnage is covered by the classification rules and standards set by the 12 members.

**ICE – Institution of Civil Engineers**
A body comprised of engineers who aim to promote education in engineering. Formed in 1818, with its headquarters in London, today it has worldwide membership.

**IESIS – Institution of Engineers and Shipbuilders in Scotland**
Originally the Scottish Shipbuilders' Association, today it provides a unique forum in which professional engineers and others can meet and discuss matters of common interest.

**ihp – indicated horsepower**
This is a measurement of the power output of an engine; it is derived from the cylinder pressure and the revolutions per minute (rpm).

**IMarEST – Institute of Marine Engineers, Science and Technology**
Founded as the Institute of Marine Engineers (IMarE) with an inaugural meeting in 1888, today the IMarEST is the first institute to bring together marine engineers, scientists and technologists into one international multidisciplinary professional body.

**IMCO – Inter-Governmental Maritime Consultative Organization**
Now IMO, see below.

**IMarE – Institute of Marine Engineers**
See IMarEST.

**IMechE – Institution of Mechanical Engineers**
Founded in Birmingham in 1847, today it is an independent engineering society headquartered in central London and representing mechanical engineers.

**IMO – International Maritime Organization**
The specialised agency of the United Nations that is responsible for safety and security at sea and the prevention of marine pollution from ships. Established as IMCO in 1948, the IMO first met in 1959.

**INA – Institution of Naval Architects**
See RINA.

**IRS – Indian Register of Shipping**
Indian classification society established as a public limited company in 1975.

**ISM Code – International Safety Management Code**
Provides an international standard for the safe management and operation of ships and for pollution prevention. The purpose of ISM Code is to ensure safety at sea, to prevent human injury or loss of life, and to avoid damage to the environment and to the ship.

**ISO – International Organization for Standardization**
ISO was formed in 1947. It is a network of the national standards institutes of different countries, and is the world's largest developer and publisher of international standards.

**JIPs – Joint Industry Projects**
At any time, LR has dozens of JIPs under way, which provide a rapid route to innovation.

**kg – kilograms**
The SI base unit of mass (equal to the mass of one litre of water).

**KR – Korean Register**
Korean classification society established in 1960.

**kW – kilowatts**
A unit of measurement mostly used for electricity (equal to 1,000 watts).

**LASH – Lighter Aboard Ship**
A system that allows a barge or lighter to be lifted onto a larger ship usually by crane. SEABEE and BACAT (barge aboard catamaran) are similar systems, but the barges are loaded using a lift below the waterline.

**lb – pound**
An imperial unit of mass equivalent to 0.45 kg

**Liberty ships**
Ships constructed in the US 1941–1945 to replace Allied merchant shipping lost during the Second World War. Over 2,700 of these ships were built using quicker methods of construction, such as welding.

**LNG – Liquefied Natural Gas**
Cooling natural gas to approximately –163°C changes it from gas to liquid. When liquefied, the gas is reduced to 1/600th of its original volume, making it economic to transport in purpose-built ships.

**Load line**
The line on a merchant ship depicting the maximum depth to which it can be loaded. The load line is affected by the area and season the ship is trading in.

**LPG – Liquefied Petroleum Gas**
Often called propane because it comprises various mixtures of propane and other similar types of hydrocarbon gases. These hydrocarbons are gases at room temperature, but turn to liquid when compressed While the distribution of LNG requires heavy infrastructure investments, LPG is more easily transported

**LR – Lloyd's Register**
The world's first classification society, founded in 1760.

**LRET – Lloyd's Register Educational Trust**
Established as an independent charity in 2004, and integrated within the LRF on 1 March 2013.

**LRF – Lloyd's Register Foundation**
A UK charity established in 2012 that funds the advancement of engineering-related education and research.

**LRTA – Lloyd's Register Technical Association**
Founded in 1920 as the Lloyd's Register Staff Association (LRSA) and renamed Lloyd's Register Technical Association in 1970.

**Maltese Cross (✠)**
Used since 1853 as part of the class notation to denote a vessel built under special survey of LR.

**Maritime Labour Convention**
The International Labour Organization's Convention, known as 'MLC, 2006' came into force in August 2013, effectively becoming binding in international law It is currently ratified by 56 ILO member states responsible for regulating conditions for seafarers on more than 80 per cent of the world's gross tonnage of ships. It establishes minimum working and living standards on those ships.

**MARPOL**
The International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted in 1973 by IMO, and covered pollution by oil, chemicals, harmful substances in packaged form, sewage and garbage. It was amended in 1978 and designated MARPOL 73/78. LR was authorised by several flag administrators to verify the compliance of vessels with MARPOL.

**MGB**
Motor gunboat.

**NECIES**
North East Coast Institution of Engineers and Shipbuilders, founded in 1884.

**nhp – nominal horsepower**
The term nominal horsepower was used to indicate the capability of early reciprocating steam engines. It was based on dimensions rather than performance and did not indicate the actual power developed by the engine

**NK – Nippon Kaiji Kyokai**
Japanese classification society, also known as ClassNK, which was founded in 1899 as Teikoku Kaiji Kyokai.

**nrt - net registered tonnage**
Net registered tonnage is derived by deducting from the gross registered tonnage the capacity unavailable for cargo, such as crew accommodation and machinery space.

**OBO – Ore/bulk/oil or oil/bulk/ore**
A ship designed to be capable of carrying liquid or dry cargoes.

**OCL – Overseas Containers Limited**
Overseas Containers Limited was a shipping container company that was founded in 1965 and was in service for 21 years.

**OILPOL**
International Convention for the Prevention of Pollution of the Sea by Oil.

**Panamax**
The largest acceptable size in order to transit the Panama Canal. Ships' lengths are restricted to 275 metres, and maximum permitted width is slightly more than 32 metres. Average deadweight of such a ship is about 65,000 to 80,000 tonnes, cargo intake usually restricted to approximately 52,500 tonnes on the Panama Canal draft.

**Paris Memorandum of Understanding (MoU)**
The Paris MoU aims to eliminate the operation of sub-standard ships through a harmonised system of port state control. It consists of 27 participating maritime administrations and covers the waters of the European coastal states and the North Atlantic basin from North America to Europe.

**PRS – Polski Rejestr Statków**
Polish classification society, established in 1936 as the Polish Register of Inland Shipping, today it also covers sea-going ships.

**PSC – Port State Control**
The inspection of foreign ships in national ports to verify that the condition of the ship and its equipment complies with the requirements of international conventions and that the ship is manned and operated in compliance with these rules.

**psi – pounds per square inch**
A unit of measurement relating to stress or pressure: 1 psi = 6,894 7529 Pascal.

**RFID – radio-frequency identification**
The use of an electronic 'tag' to automatically identify an item. The tags can be active or passive and are used for a wide range of items, from supermarket foods to pets, cars and super-tankers.

**RI – Registro Italiano Navale**
Italian classification society, founded in 1861. Sometimes abbreviated to RINA or RI.

**RINA – Royal Institution of Naval Architects**
Previously the Institution of Naval Architects (INA), founded in 1860.

**Risk management**
This term is used in many business sectors, including finance and insurance. LR's concern with risk management is in relation to the technical, safety and commercial aspects of our clients' assets – ships, oil rigs, industrial plant and railways.

**RMS – Royal Mail Ship**
Prefix placed before the name of a British merchant ship licensed to carry mail.

**RNLI – Royal National Lifeboat Institution**
Founded by Sir William Hillary in 1824 as the National Institution for the Preservation of Life from Shipwreck.

**ro-ro – roll-on, roll off**
A type of vessel designed to carry both passengers and wheeled cargo such as cars, rail carriages and trucks.

**rpm – revolutions per minute**
The rotational speed of the machinery and shafts.

**RS – Russian Maritime Register of Shipping**
Russian classification society, established in 1913.

**SAR**
International Convention on Maritime Search and Rescue, adopted in 1979.

**SEABEE – SeaBarge**
Vessels with a lifting system located at the stern of the carrier ship. See also LASH.

**shp – shaft horsepower**
The power delivered to the propeller shafts of a steamship, or to vessels powered by diesel engines or nuclear power.

**SINA – Society for the Improvement of Naval Architecture**
Formed in London in 1791 as a forum for the exchange of ideas and furtherance of knowledge.

**SMMI - Southampton Marine and Maritime Institute**
A centre of excellence, bringing together research, innovation and education communities from universities, research institutes, industry and governments.

**SNAME – The Society of Naval Architects and Marine Engineers**
Founded in 1893, today its mission is to advance the art, science and practice of naval architecture, marine engineering, ocean engineering and other marine-related professions.

**SOLAS – Safety of Life at Sea**
International Convention for Safety of Life at Sea; first conference held in 1913 in response to the sinking of the *Titanic*

**Springing and whipping**
The springing of a ship is the continual vibration of the hull girder caused by oscillating wave loads along the hull of a ship. Whipping is the transient vibration from the bow impact.

**Supramax**
Bulk carriers with a capacity between 50,000 and 60,000 dwt. These 'bulkers' are well suited for small ports with length and draught restrictions, or ports lacking transhipment infrastructure.

**SWATH**
Small waterplane area twin hull.

**SWOPS**
Single well oil production ship.

**teu – twenty-foot equivalent unit**
The measure used for container capacity, a teu is a volume measurement equal to one standard 20-foot length container.

**TID – Technical Investigations Department**
A Lloyd's Register department within the Marine Consultancy, TID is responsible for providing engineering assessments and evaluations in order to minimise potential risks. TID's areas of in-depth expertise include hydrodynamics, marine failure investigation, vibration and noise, analysis, trials and measurements.

**TKK – Teikoku Kaiji Kyokai**
Japanese Classification society founded in 1899 as the Imperial Japanese Marine Corporation. See NK, above.

**Ton**
A unit of measure derived from tun, which indicated the capacity of a wine cask. Tons refers to cubic capacity, and is based upon 100 feet cubed, or 2.83 metres cubed equals one ton

**Ton-mile**
A unit of freight transportation equivalent to a ton of freight moved one mile.

**Tons burthen**
An estimate of the weight of cargo that could be carried, this was in common usage during the age of sail.

**ULCC – Ultra Large Crude Carrier**
These are the biggest ships in the world, currently from 250,000 to 500,000 dwt and up to 1,300 feet long. Their size restricts them to the comparatively few ports that can handle them, and they are best suited for the longest routes.

**ULCS – Ultra Large Containership**
Typically with a capacity of over 11,000 teu.

**UMS – Unattended Machinery Space**
Denotes a classification society notation which indicates that the ship can operate with unattended machinery for agreed periods of time.

**VLCC – Very Large Crude Carrier**
These tankers are usually 180,000–220,000 dwt. Although they can be as long as a ULCC, their draught and beam are considerably less. This enables them to pass through the Suez Canal, and they are also more flexible in terms of ports and handling facilities.

**Watt**
A derived unit of power named after the eighteenth century engineer James Watt. It is defined as a joule per second used to express the rate of energy conversion or transfer with respect to time

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## Interviews

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# Index

**Note: LR denotes Lloyd's Register.**
**Cities and towns are listed under the relevant country excepting in the case of the UK, for which longer entries are indexed separately.**

**M**

**N**

**T**